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THE MESOSCALE DISTRIBUTION OF RAINFALL IN CALIFORNIA RAINSTORMS

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THESIS

THE MESOSCALE DISTRIBUTION OF

RAINFALL IN CALIFORNIA RAINSTORMS

by

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March 1974

The Mesoscale Distribution of

Rainfall in California Rainstorms

by

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ABSTRACT

The rainfall patterns in California, produced by six storms of the 1972-1973 winter storm season, were analyzed in detail in order to determine the mesoscale distribution of precipitation with respect to the larger-scale synoptic systems.

It was found that the structure of precipitation patterns primarily reflected orographic influences rather than mesoscale circulation features intrinsic to the larger-scale system. Heaviest amounts of rainfall were concentrated primarily along the major mountain ranges with much lesser amounts in the interior valleys.

Storms with fronts (Class II) produced more precipitation in the inland valleys and more convective type precipitation than storms without well defined fronts (Class I). Storms with fronts exhibited geographically fixed bands of precipitation that paralleled the surface front. An elongation of precipitation in the direction of the 500 mb flow was found in one case study.

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ACKNOWLEDGEMENTS

I wish to express my deep gratitude to Professor M. Steven Tracton for his patient guidance and advice. Without his help, this research would have been considerably more time consuming and difficult.

My appreciation is extended to the Naval Weather Service Environmental Detachment at Asheville, North Carolina for supplying microfilm data and tipping-bucket rain gauge traces vital to this research.

Finally, I want to thank my wife, Joan, who so unselfishly gave her time, devotion and moral support, without which the completion of this thesis would not have been possible.

I. INTRODUCTION

Recent research of sub-synoptic scale phenomena has revealed the necessity of modifying the classical textbook model of uniform, steady precipitation in advance of the surface warm front, and brief, showery precipitation associated with the surface cold front.

Elliott and Hovind (1964), in a study of Pacific storms entering the Santa Barbara area of California during the 1960-1963 winter storm seasons, found organized convection bands 20 to 40 miles wide, centered some 30 to 60 miles apart in advance of the storm system. Evidence of increased precipitation rates was found within these bands, and each band was tracked for over 100 miles. Convective cells within the bands had a diameter on the order of two to four miles and accounted for the bulk of precipitation.

It is to be noted that the observation network utilized by Elliott and Hovind consisted of coastal and offshore island stations, as well as extensive offshore flight observations. Thus, orographic influences played a minimal role upon the distribution of precipitation, except at stations situated immediately along the coastline.

In a case study of the mesoscale distribution of precipitation in a warm sector depression, Atkinson and Smithson (1972) found large mesoscale (approximately 200 km) and small mesoscale (approximately 50 km) areas of rainfall. In addition, it was noted that the smaller mesoscale rain areas moved parallel to the surface fronts and traced out the larger mesoscale rain areas. Tweedy (1965) found mesoscale bands of

heavy precipitation elongated in the direction of the 500 mb flow in 15 of 19 storms affecting the eastern United States.

The objective of the study presented here is to describe the mesoscale distribution of precipitation in California rainstorms. Knowledge of characteristic sub-synoptic precipitation patterns should be useful to meteorologists, hydrologists and forestry officials to assist in flood prediction, crop protection and planting, and the determination of watershed input for power production.

Six storms of the winter storm season of 1972-1973 were selected for analysis. Charts of hourly precipitation amounts were drawn for each storm in order to determine the mesoscale distribution of precipitation with respect to the larger-scale synoptic systems. Attention, at first, was focused upon such items as the convection bands noted by Elliott and Hovind, the large and small mesoscale rain areas noted by Atkinson and Smithson, and the elongation of heavy precipitation in the direction of the 500 mb flow as noted by Tweedy. As will be seen in subsequent sections, however, although some indication of said features were observed, it was found that the topographic influence of the coastal mountain ranges and the Sierra Nevada range dominated the precipitation patterns. Precipitation was largely concentrated in bands paralleling the mountain ranges, with smaller amounts falling in the central valleys. Thus, the structure of precipitation patterns primarily reflected orographic influences rather than mesoscale circulation features intrinsic to the larger-scale synoptic systems.

The following section discusses the sources of data and methods of analysis utilized in the case studies. Section III presents the

results of the study and a detailed discussion of two storms, while Section IV presents an overall summary and conclusions. Section V presents recommendations for further research.

II. PROCEDURE

A. CRITERIA FOR STORM SELECTION

Six storms were analyzed in detail for this study. The principal criterion for storm selection was that it produce significant rainfall in California, as deduced by reference to the occurrence of mudslides or flooding in the publication of Climatological Data (see below).

B. SOURCES OF DATA

1. Hourly Precipitation Data

Hourly Precipitation Data is a pamphlet published monthly for each state by the U. S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), Environmental Data Service (EDS). The Hourly Precipitation Data lists one-hour precipitation amounts for each hour of each day of the month. The network of stations in California at which hourly amounts are recorded is shown in Figure 1, and the topography of the state is shown in Figure 2. In addition to hourly amounts, daily and monthly precipitation totals are also listed.

2. Climatological Data

Climatological Data is a pamphlet published monthly for each state by the U. S. Department of Commerce, NOAA, EDS. This pamphlet contains a "Special Weather Summary" which cites instances of unusual meteorological events during the month. Daily and monthly precipitation totals, as well as an index of the latitude, longitude and elevation of stations depicted in Figure 1 are also listed.

3. Standard Meteorological Charts

The sea-level pressure analyses, and the 700 mb and 500 mb height and vorticity analyses distributed over the National Weather Service (NWS) facsimile network were utilized to assess the large-scale synoptic situation for each case study.

4. Continuous Rain Gauge Traces

Tipping-bucket rain gauge traces were available for the NWS station at Sacramento. The tipping-bucket rain gauge permits one to assess the continuous temporal variation of precipitation rate and, hence, to differentiate between steady stratiform rain and rainfall fluctuating rapidly in space and time as is characteristic of convective showers.

C. METHODS OF ANALYSIS

The six storms analyzed in this investigation were divided into two classes. Class I storms were low-pressure areas which did not possess well defined frontal systems on the NWS surface synoptic charts. Class II storms, on the other hand, exhibited well defined surface fronts.

For each storm, charts of total rainfall amounts and individual hourly amounts were constructed. These charts were the principal basis for determining the mesoscale distribution of precipitation.

In order to supplement information gleaned from the tipping-bucket traces at Sacramento with respect to the importance of convectively produced precipitation, rainfall histograms of successive one-hour precipitation amounts were constructed for selected stations for each case study. Although the instantaneous precipitation rates cannot be

determined from the histograms, the magnitude of the hourly precipitation totals can be assessed so as to give some indication of whether the precipitation was of the continuous stratiform type or produced primarily by convective showers. More specifically, differences in consecutive one-hour rainfall amounts exceeding 0.2 in - 0.3 in imply precipitation produced largely by convective cells.[1]

In order to determine the existence of moving mesoscale precipitation bands as noted by Elliott and Hovind, cross sections of hourly rainfall amounts through successive reporting stations were constructed (e.g., Figures 3 and 4). In such cross sections, the existence of a mesoscale band of precipitation traveling in a direction parallel to the line of the cross section would appear as a precipitation peak at successively later times at stations affected by the band.

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[1]Personal communication with Professor M. S. Tracton, Department of Meteorology, U. S. Naval Postgraduate School, February, 1974.

III. RESULTS AND DISCUSSION

In this section the general results of storm analyses are presented. A discussion of selected cases then follows in order to highlight pertinent points.

A. CLASS I STORMS

Of the six case studies, those of 11 October 1972 and 11 February 1973 were categorized as Class I storms. In Class I storms, the distribution of heavy precipitation was primarily dominated by topography. That is, the rainfall was oriented primarily along the major mountain ranges. As can be seen from the charts of total rainfall in Figures 5 and 6, only relatively light amounts fell in the flat valley regions of the interior portion of the state. The precipitation of both storms was primarily of the continuous type, as can be seen, for example, from the tipping-bucket trace for Sacramento on 11 October (Figure 7). The trace shown is representative of both Class I storms. Note that, although rainfall was primarily stratiform, the sharp peaks in the rainfall rate indicate the presence of some convectively produced precipitation. This is evident also from the large variation in consecutive one-hour precipitation amounts in rainfall histograms constructed for selected stations. Figure 8 presents a histogram for one such station for the 11 October case study, while Figure 9 depicts a histogram of a station for the 11 February storm.

As can be seen in Figures 10 and 11, relatively insignificant amounts of precipitation were produced in the Los Angeles area when

there was a relatively weak southwesterly gradient (i.e., geostrophic winds less than 10 kts). On the other hand, a southwesterly gradient implying geostrophic wind speeds greater than 10-15 kts produced significant precipitation, as evidenced in Figures 12 and 13. The southwesterly flow provided an influx of warm, moist, maritime air at lower levels, which subsequently was lifted orographically by the coastal mountains. When the winds changed such that there was a northwesterly component, or southwesterly wind speeds were less than about 10 kts, precipitation quickly ceased. It is interesting to note that this behavior was not found in any other regions of the state, but pertained solely to the Los Angeles area.

One apparent difference in the overall distribution of rainfall between the two Class I storms was an elongation of heavy precipitation in the direction of the 500 mb flow in the 11 October case. As previously mentioned, Tweedy noticed such an elongation in his study of storms affecting the eastern United States. Because the 11 October storm displayed the elongation of precipitation, as well as most of the general features of Class I storms noted above, that case was selected for detailed discussion.

Case Study, 11 October 1972

A stationary low pressure center (Figure 14) approximately 100 miles west of the California coastline, in conjunction with pronounced positive vorticity advection in advance of the associated 500 mb trough, provided the synoptic-scale background conducive to heavy precipitation in northern and central California.

Cyclonic circulation about the inverted trough extending from North Central Mexico to the Los Angeles area (Figure 14) produced offshore flow which suppressed precipitation in that area.

As seen previously in the chart of total rainfall (Figure 5), the distribution of precipitation was dominated primarily by topography in that heaviest rainfall lay along the major mountain ranges with relatively lighter amounts in the flat valley regions of the interior. The tipping-bucket rain gauge trace at Sacramento (Figure 7) and rainfall histograms at selected stations (e.g., Figure 8) show that the precipitation was primarily of the continuous type, though there is indication of some convectively produced rainfall.

As previously mentioned, an elongation of the precipitation pattern was found in the direction of the 500 mb flow. More specifically, as can be seen by reference to the charts of one-hour rainfall amounts at two-hour intervals presented in Figures 16-20, precipitation extended northeastward from the San Francisco Bay Area toward the Sacramento Valley in line with the southwesterly 500 mb flow (Figure 15).

In an effort to determine the nature of the elongation of the precipitation patterns, cross sections of hourly precipitation amounts were constructed along lines connecting successive reporting stations both perpendicular (Figure 21) and parallel (Figure 22) to the 500 mb flow. The cross sections (Figures 23 and 24) suggest the existence of a mesoscale band of precipitation moving at a speed of 10-15 kts in the direction of the 500 mb flow. The peak in precipitation at approximately 1300 GMT appearing in Figure 23 seemingly reflects a

band of precipitation that had moved inland over the Bay Area from the offshore low pressure center. Further, the fact that the rainfall peaks moved from stations four to eight in Figure 24 tended to confirm the existence of a band of precipitation moving toward the northeast from the Bay Area. It is to be noted that this is the only instance in any of the cases studied that a band could be shown to exist.

A possible explanation for the elongation of the rainfall distribution from the San Francisco area towards Sacramento, in terms of the precipitation band, is as follows. When the band moved inland, the coastal mountains (Figure 2)north and south of the San Francisco Bay Area acted orographically to enhance precipitation over the mountainous terrain and, hence, deplete the northern and southern portions of the band of its moisture. That portion of a band which passed through the relatively flat terrain of the Bay Area, however, deposited precipitation continuously as it passed further inland. Thus, passage of the band through the relatively flat terrain of the Bay Area, i.e., flat with respect to the terrain immediately to the north or south, was likely responsible for the elongation of precipitation towards the Sacramento Valley. Note that inherent in the discussion is the fact that topography, vice mesoscale structure intrinsic to the synoptic-scale system, was the dominant influence in determining the distribution of precipitation at the ground. Except for the instance just described, topography completely obscured the existenceof mesoscale areas or bands imbedded in the larger-scale circulation.

B. CLASS II STORMS

Of the six case studies, the storms of 13-14 November 1972, 15-16 November 1972, 17-18 January 1973, and 9-10 February 1973 were categorized as Class II storms.

As was the case in Class I storms, topography exhibited a dominating influence on the precipitation patterns, such that most precipitation fell along the major mountain ranges; however, precipitation in the flatter valleys of the interior portion of the state was notably heavier than in Class I storms. This can be seen from the charts of total rainfall presented in Figures 25-28 for each of the Class II storms. Note also that larger amounts of precipitation fell over the major mountain ranges in Class II storms, presumably as a result of the combination of both frontal and orographic lifting.

Periods of continuous precipitation in Class II storms exhibited a considerable degree of convective shower activity as, for example, demonstrated by the tipping-bucket trace for Sacramento shown in Figure 29. This graph is representative of each of the Class II storms. Additional evidence of convective precipitation was obtained from histograms of rainfall constructed for selected stations throughout the state. Figure 30, for example, depicts a histogram of one location for 18 January. Note also that Class II storms produced much higher rates of convectively produced rainfall than Class I storms. The maximum rainfall rates at Sacramento for Class II and Class I storms were 3.6 in/hr and 0.6 in/hr, respectively.

As can be seen in Figures 31 and 34, little or no precipitation was produced in the Los Angeles area when there was a relatively weak southwesterly gradient (i.e., geostrophic winds less than 10 kts).

On the other hand, a southwesterly gradient implying geostrophic wind speeds greater than 10-15 kts produced significant precipitation, as evidenced in Figures 32 and 37.

A distinguishing characteristic of Class II storms was small areas of precipitation with dimensions on the order of 40-60 mi in length, 20-40 mi in width, and oriented parallel to the surface front. The areas appeared to reflect an interaction of frontal passage and the topographic influence of the mountain ranges. That is, individual areas were produced as a consequence of frontal passage over mountainous regions conducive to orographic precipitation. Though individual areas were geographically fixed, the generation of new and dissipation of old areas gave the impression of a moving mesoscale band of precipitation oriented parallel to the surface front. There was some evidence of small cells imbedded within the areas and moving through them perpendicular to the axis of the front. These small cells could be tracked on occasion for two to three hours, and might have contributed to a slight elongation of the rainfall patterns perpendicular to the axis of the front as found by Atkinson and Smithson (1972).

In order to further evaluate the general features of Class II storms, the storm of 17-18 January 1973 was selected for more detailed discussion.

Case Study, 17-18 January 1973

A surface occluded front that penetrated the northern California coastal mountain ranges in the late evening of 17 January (Figure 31) provided conditions conducive to significant precipitation over the northern regions of the state. A strong southwesterly pressure gradient necessary for the onset of precipitation in the Los Angeles area had been established by 0800 GMT 18 January. It is notable,

however, that precipitation did not begin there until approximately 1400 GMT, presumably because of the absence of significant positive vorticity advection aloft over the area until that time. Thus, broadscale ascent, as would be implied by positive vorticity advection, in addition to the orographic lifting of the warm moist air from the southwest, was necessary for significant rainfall.

Upon passage of the surface front through the Los Angeles area (Figures 32 and 33) precipitation reached a maximum and then decreased rapidly, apparently because of the influence of drier northwesterly winds immediately behind the front.

It is of interest to note that precipitation in the central and northern portions of the state did not exhibit a rapid decline after passage of the surface front. In these regions, precipitation continued long after frontal passage, in spite of the northwesterly winds, as a result of broadscale positive vorticity advection aloft.

As mentioned earlier, Class II storms exhibited small areas of precipitation oriented parallel to the axis of the surface front. One can see the spatial relationship between such areas and the surface front in the charts of hourly precipitation totals at three-hour intervals presented in Figures 34 to 41, that the maxima in precipitation are clearly related to the interaction of frontal passage and topographic features. Precipitation begins with the approach of the front and terminates shortly after its passage, with the spatial distribution clearly controlled by the orographic influence of the mountains. Heaviest rainfall occurs over mountainous terrain with much lesser amounts over the valleys.

In order to determine whether the small precipitation areas were moving or geographically fixed, cross sections of hourly precipitation

amounts were constructed along lines connecting successive reporting stations both perpendicular (Figure 42) and parallel (Figure 43) to the surface front. On the basis of the cross sections (Figures 44 and 45), one can conclude that the precipitation peaks remained geographically fixed, rather than move with the front as first appearances of the plots of hourly totals in Figures 34-41 might indicate. That is, rather than progress with the front, precipitation areas formed ahead of the front over regions orographically conducive to precipitation, remained geographically fixed as the front passed, and dissipated soon after the frontal passage. It was the combination of new areas forming ahead of the front and old areas dissipating behind it that gave the erroneous impression of areas moving with the front. The new outbreaks of rainfall ahead of the front were a combined result of positive vorticity advection, frontal lifting, and the orographic influence of the mountainous terrain.

It is to be noted that the small areas of precipitation, in that they were stationary, were not of the same type as those mentioned by Elliott and Hovind (1964); however, there was evidence of smaller cells imbedded within the precipitation areas which moved through them in a direction perpendicular to the front. These cells could occasionally be tracked for two to three hours and are thought to have contributed to elongations of the precipitation pattern perpendicular to the frontal axis, as can be observed in Figures 34-41. Evidence of a cell can be seen from the small precipitation peak that moves from stations four to seven at approximately 0000 GMT in Figure 44. As previously mentioned, Atkinson and Smithson, in a study of a warm sector depression, found similar cells which traced out elongated precipitation areas as they moved.

IV. SUMMARY AND CONCLUSIONS

It was found that storms with fronts (Class II) produced more convective type shower activity and released greater amounts of moisture over the mountain ranges and inland valley regions than storms without well defined frontal systems (Class I).

Storms with fronts exhibited small precipitation areas with dimensions on the order of 40-60 mi in length and 20-40 mi in width, oriented parallel to the surface front. Individual areas, contrary to the observations of Elliott and Hovind (1964), however, were geographically fixed over areas topographically conducive to precipitation. There was some evidence of smaller cellular precipitation areas imbedded within the larger mesoscale areas and moving in the direction of the front. These cells could sometimes be tracked for two to three hours, and likely contributed to an elongation of the precipitation patterns in the direction of the front in a manner observed also by Atkinson and Smithson (1972).

An elongation of heavy precipitation in the direction of the 500 mb flow noted by Tweedy (1965) in a study of storms affecting the eastern United States was observed in only one of the six case studies in this investigation.

In addition, it was found that in order for significant precipitation to occur in the Los Angeles area, a southwesterly pressure gradient implying geostrophic surface winds in excess of 10-15 kts was necessary.

In conclusion, it was seen that although California winter rainstorms demonstrated some of the mesoscale characteristics intrinsic to synoptic-scale systems noted in previous studies, the pronounced topographic features of California dominated the distribution of precipitation such that heavy precipitation was concentrated primarily along the major mountain ranges with much lesser amounts falling in the interior valleys.

V. RECOMMENDATIONS

The convection bands responsible for the bulk of heavy precipitation noted by Elliott and Hovind in their 1964 study of Pacific storms entering the Santa Barbara area of California were not tracked further inland than stations immediately along the coastline. In this respect, a study utilizing a mesoscale reporting net situated along the coastline and located within an area of sufficient radar coverage should probably be conducted to determine how far inland such bands may be tracked before the topographic influence of the mountain ranges begins to dominate the precipitation patterns.

Figure 1. Precipitation Reporting Stations for California.

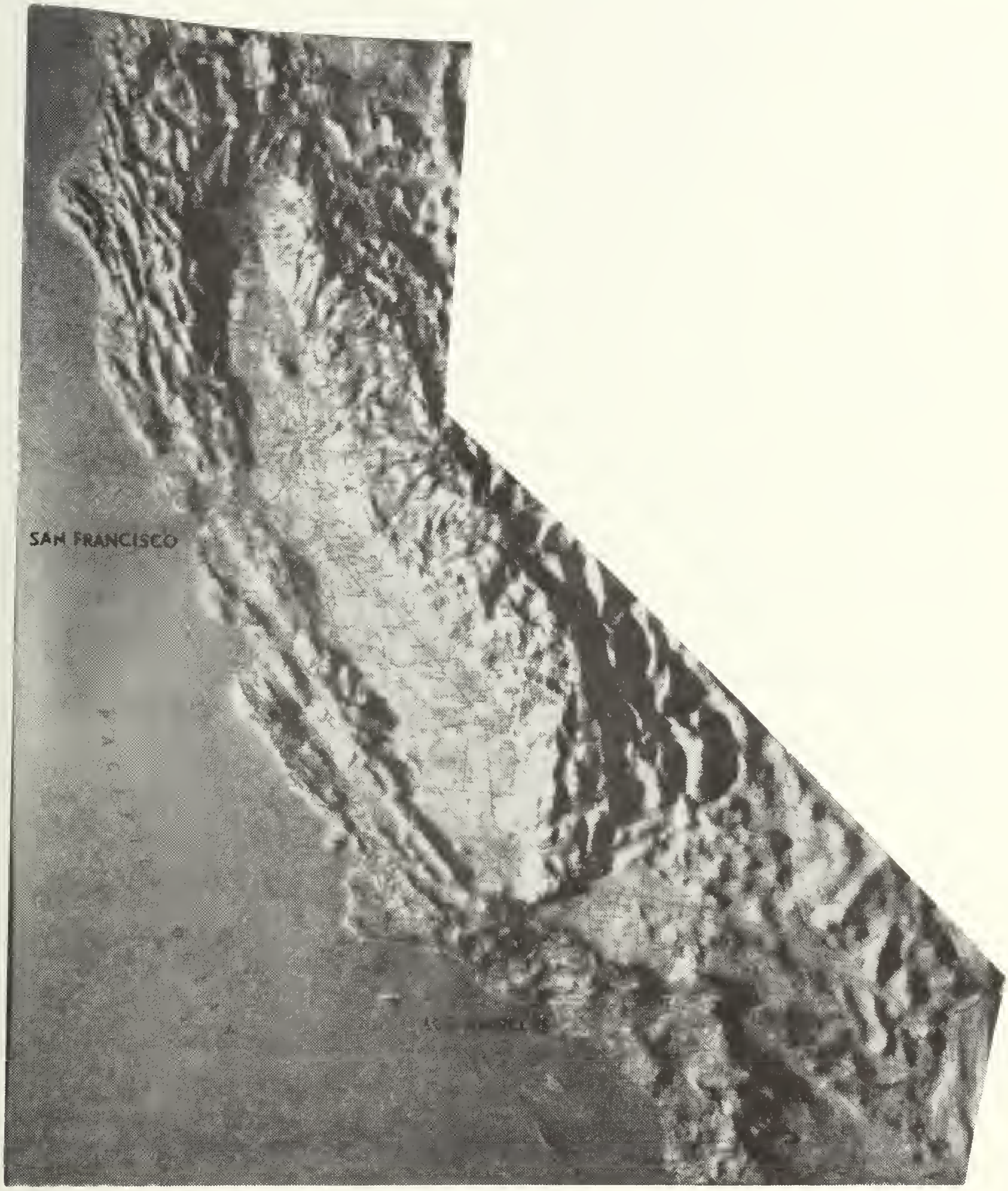

Figure 2. Topography of California.

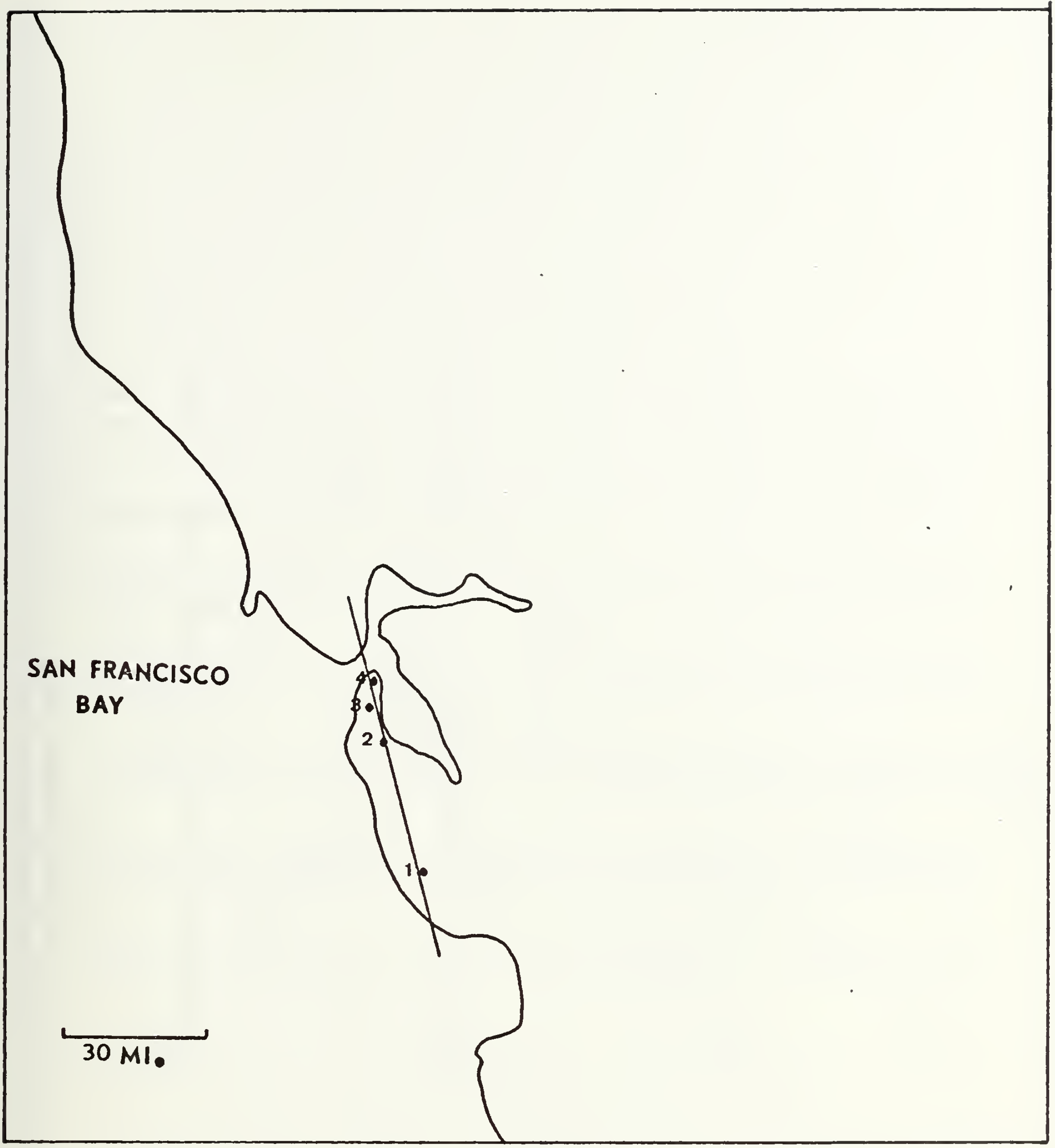

Figure 3. Stations Utilized in Precipitation Cross Section of Figure 4.

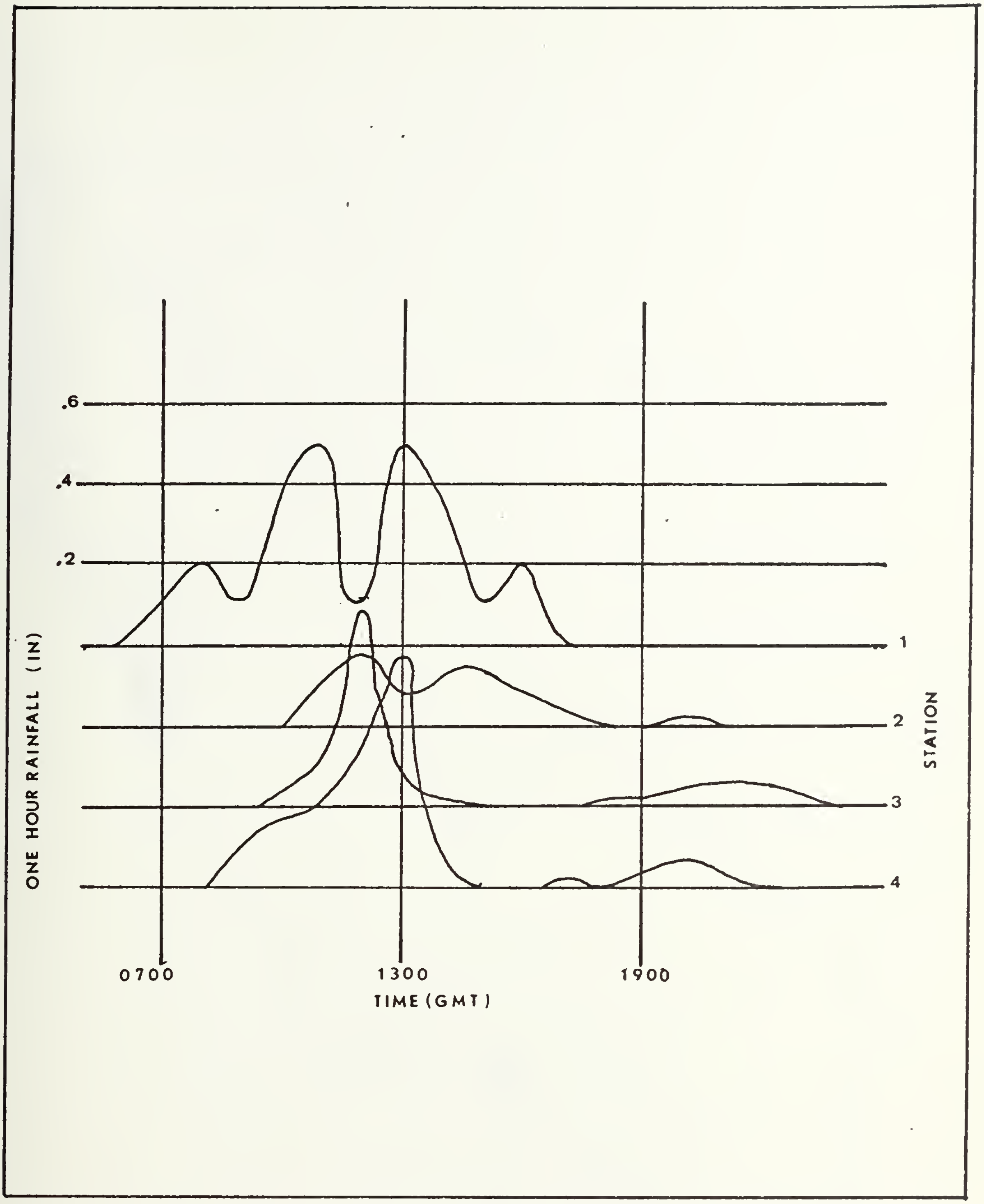

Figure 4. Hourly Rainfall Amounts Vs. Time at Stations Indicated in Figure 3.

Figure 5. 24-Hour Precipitation for 11 October 1972 (0.5 in isohyets).

Figure 6. 24-Hour Precipitation for 11 February 1973 (1.0 in isohyets).

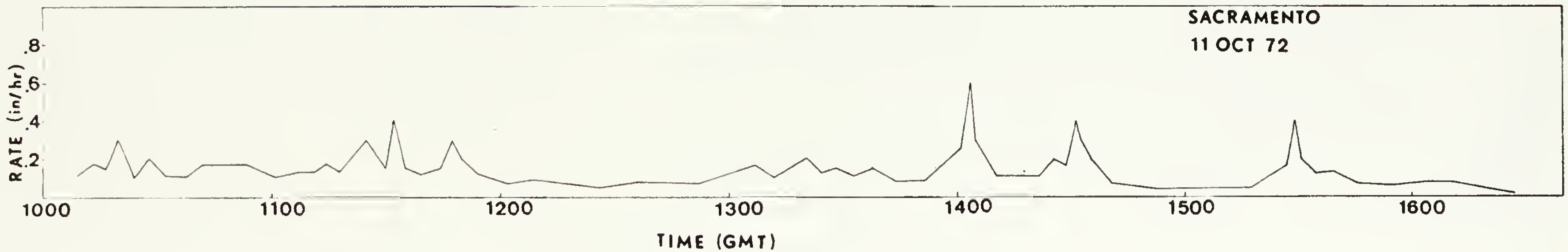

Figure 7. Tipping-bucket rain gauge trace for Sacramento, California on 11 October 1972.

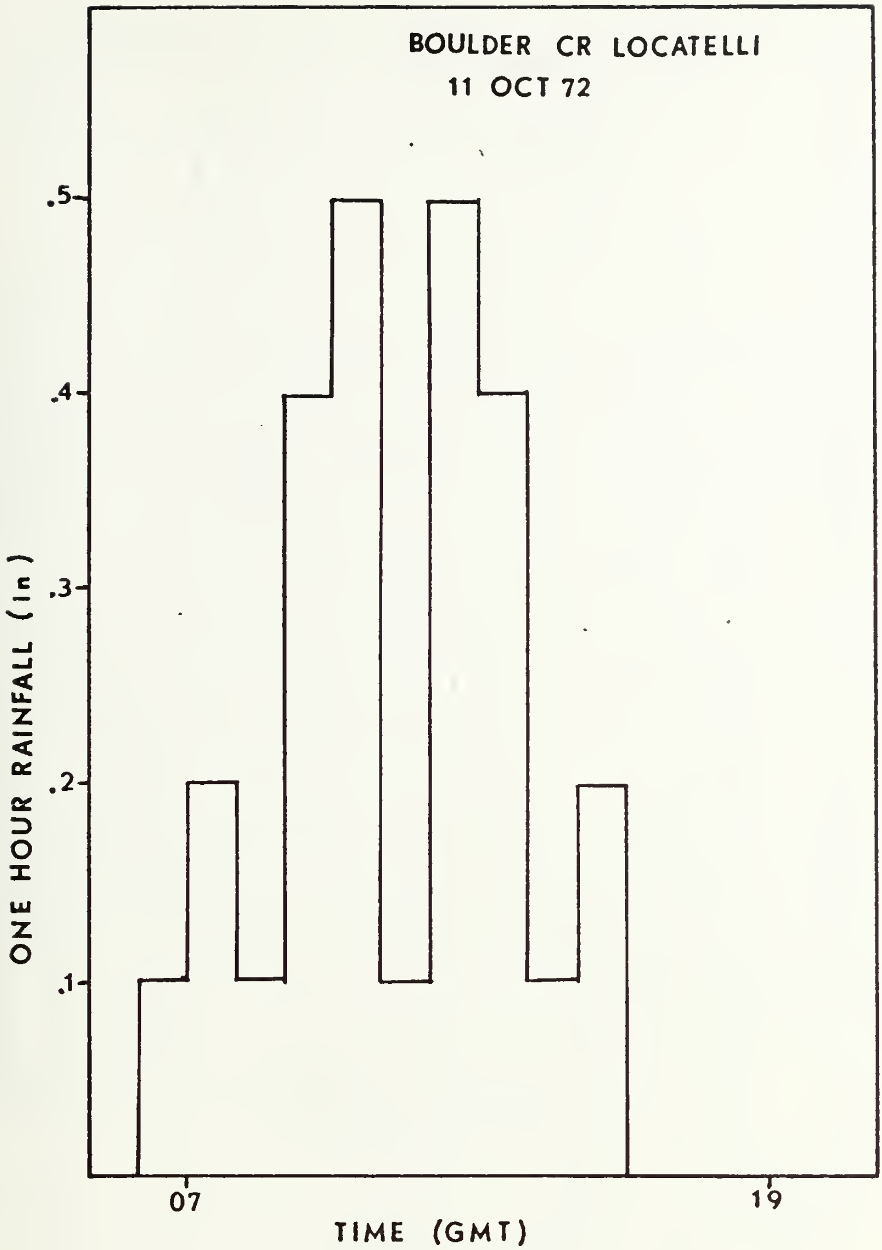

Figure 8. Histogram of Hourly Rainfall at Boulder Creek Locatelli.

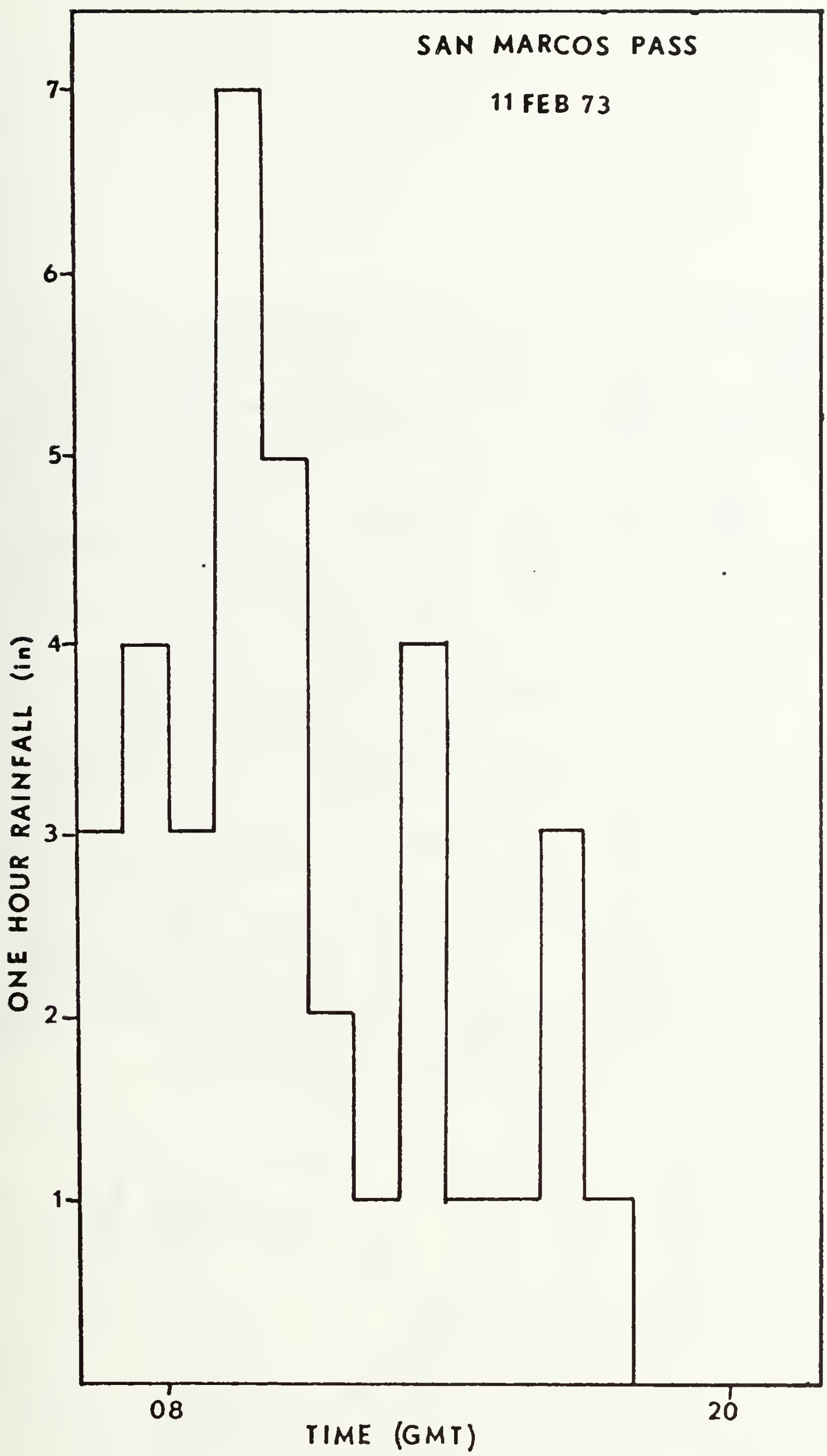

Figure 9. Histogram of Hourly Rainfall at San Marcos Pass.

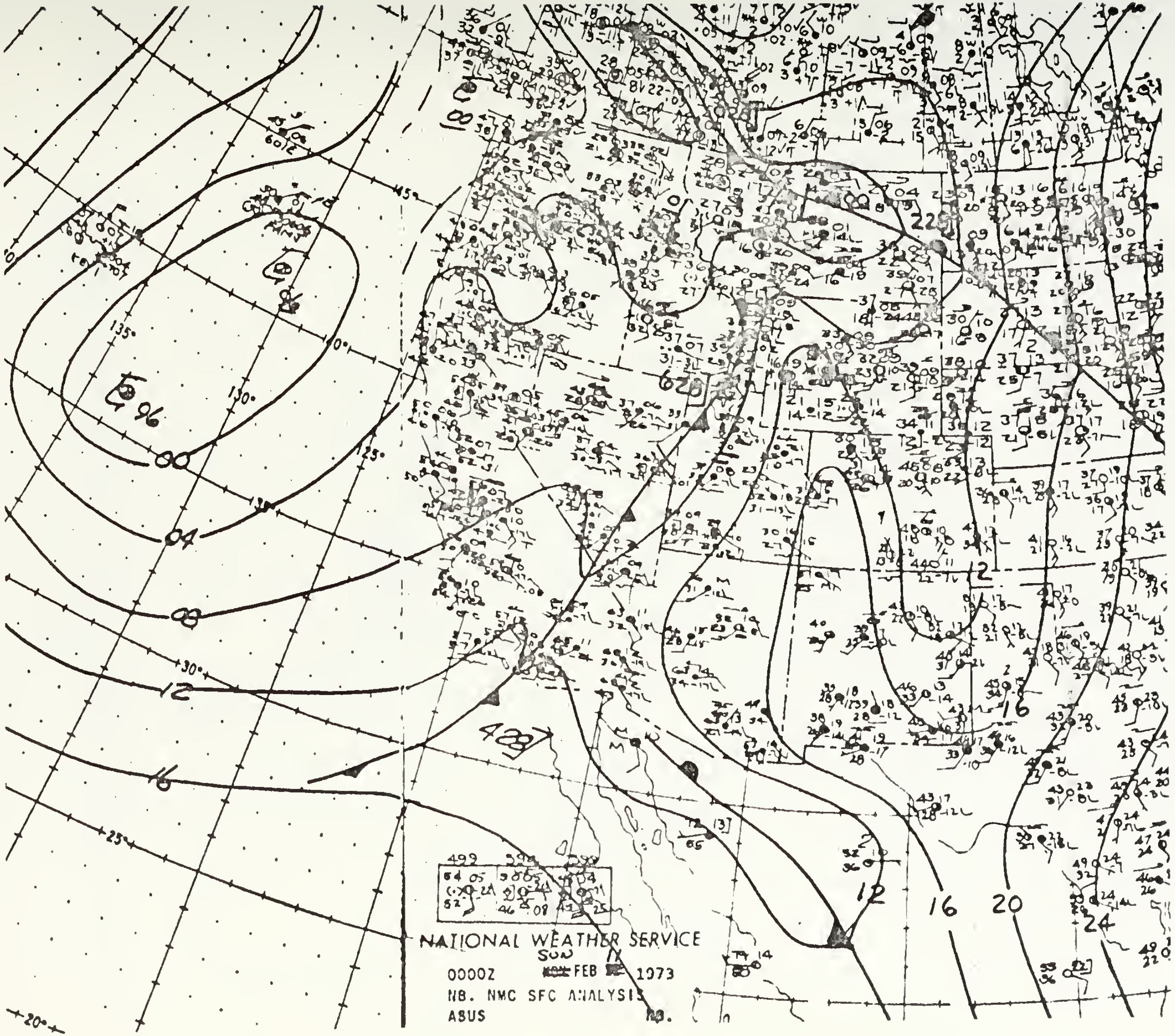

Figure 10. Surface Synoptic Chart for 0000 GMT on 11 February 1973.

Figure 11. One-Hour Precipitation Totals, 2300-0000 GMT on 10-11 February 1973 (0.1 in isohyets).

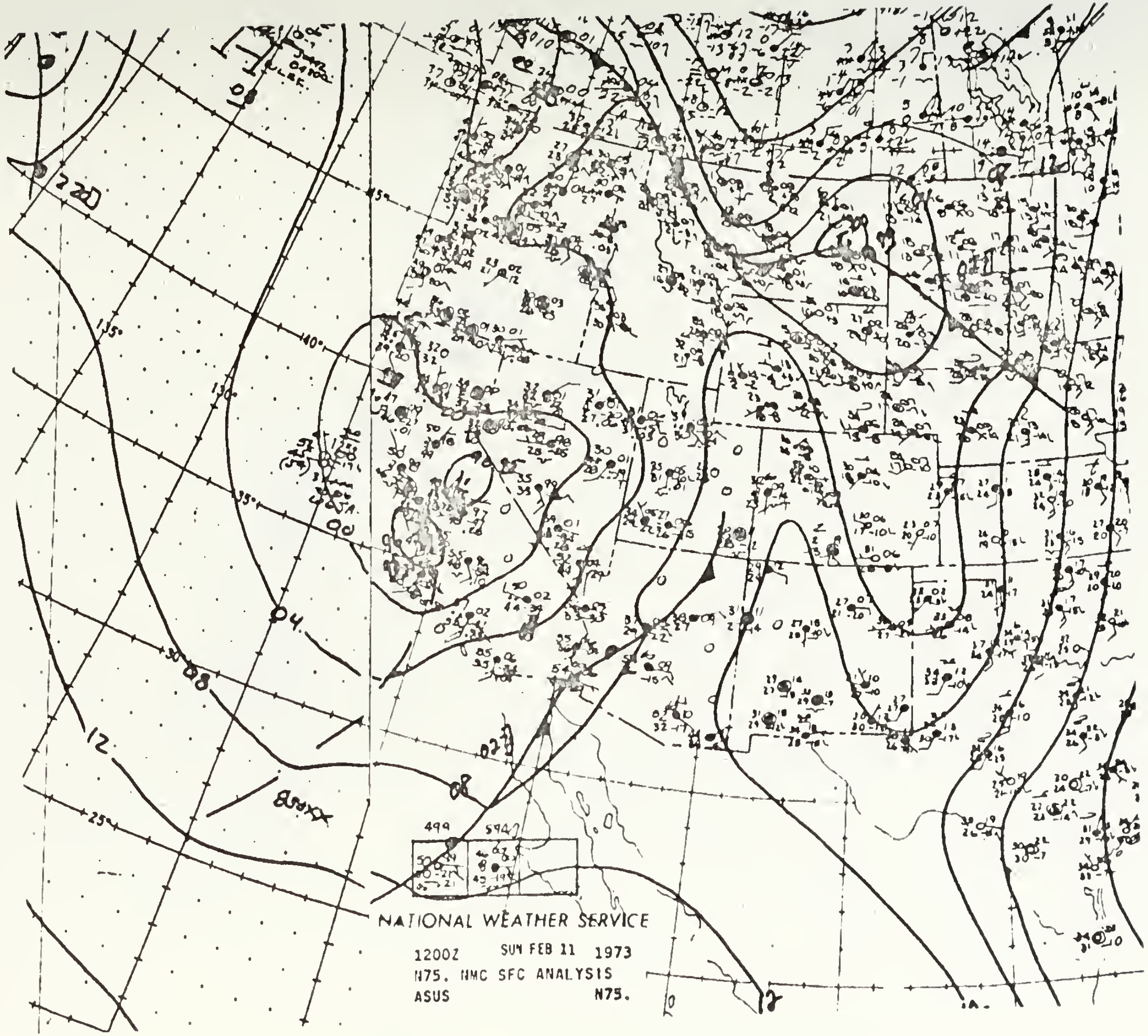

Figure 12. Surface Synoptic Chart for 1200 GMT on 11 February 1973.

Figure 13. One-Hour Precipitation Totals, 1100-1200 GMT on 11 February 1973 (0.1 in isohyets).

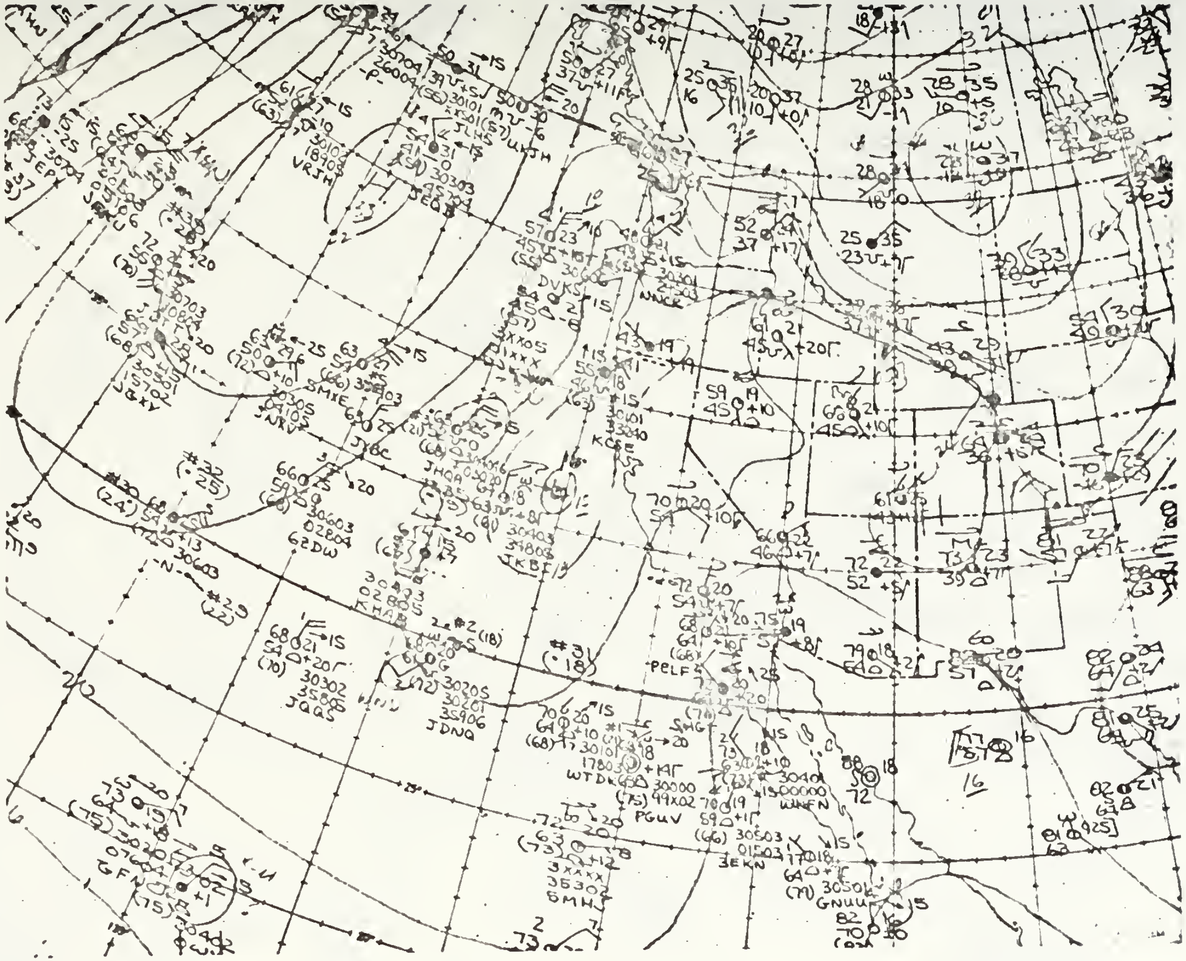

Figure 14. Surface Synoptic Chart for 1800 GMT on 11 October 1972.

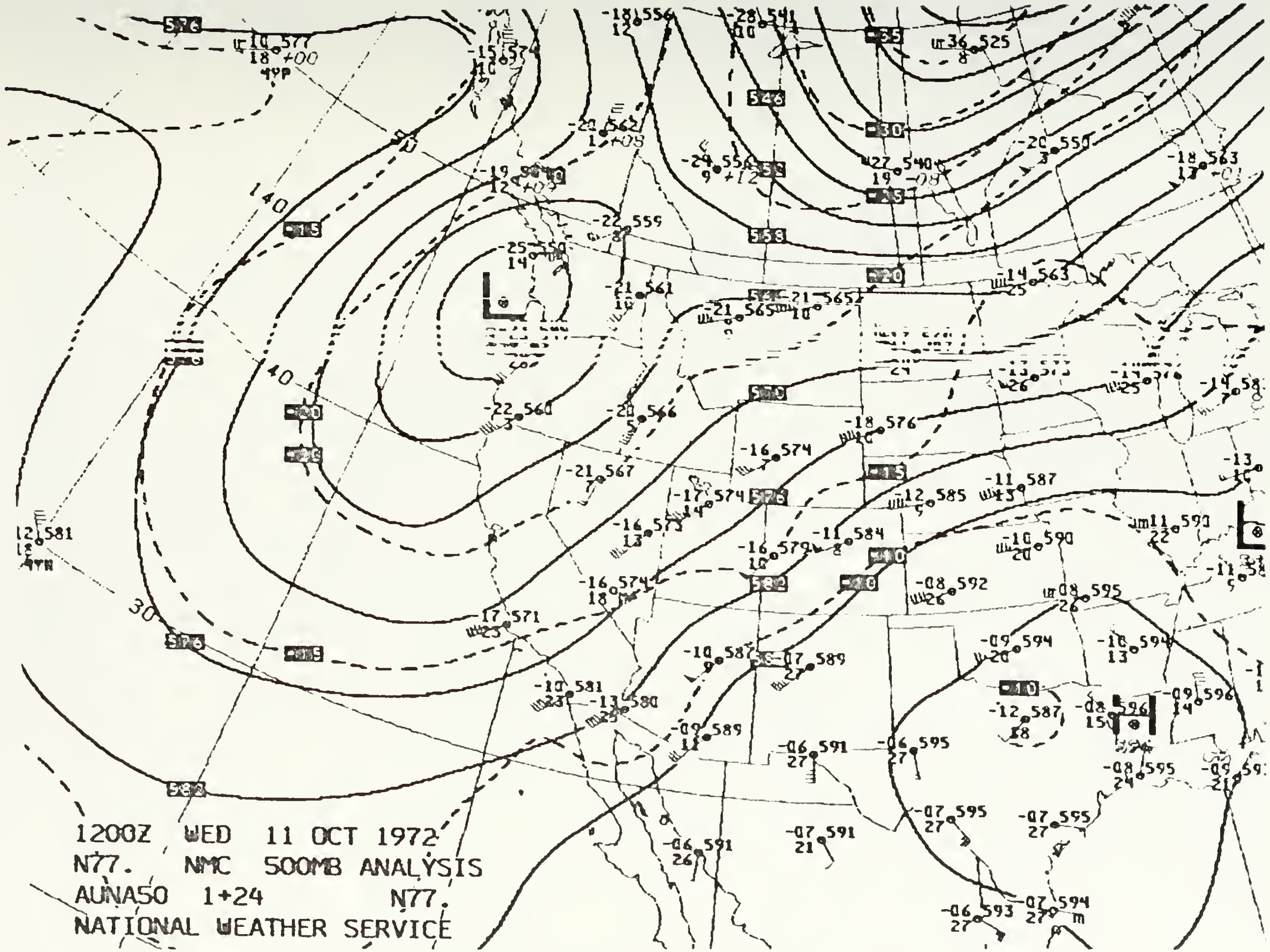

Figure 15. 500 mb Analysis for 1200 GMT on 11 October 1972.

Figure 16. One-Hour Precipitation Totals, 0700-0800 GMT on 11 October 1972 (0.1 in isohyets).

Figure 17. One-Hour Precipitation Totals, 0900-1000 GMT on 11 October 1972 (0.1 in isohyets).

Figure 18. One-Hour Precipitation Totals, 1100-1200 GMT on 11 October 1972 (0.1 in isohyets).

Figure 19. One-Hour Precipitation Totals, 1300-1400 GMT on 11 October 1972 (0.1 in isohyets).

Figure 20. One-Hour Precipitation Totals, 1500-1600 GMT on 11 October 1972 (0.1 in isohyets).

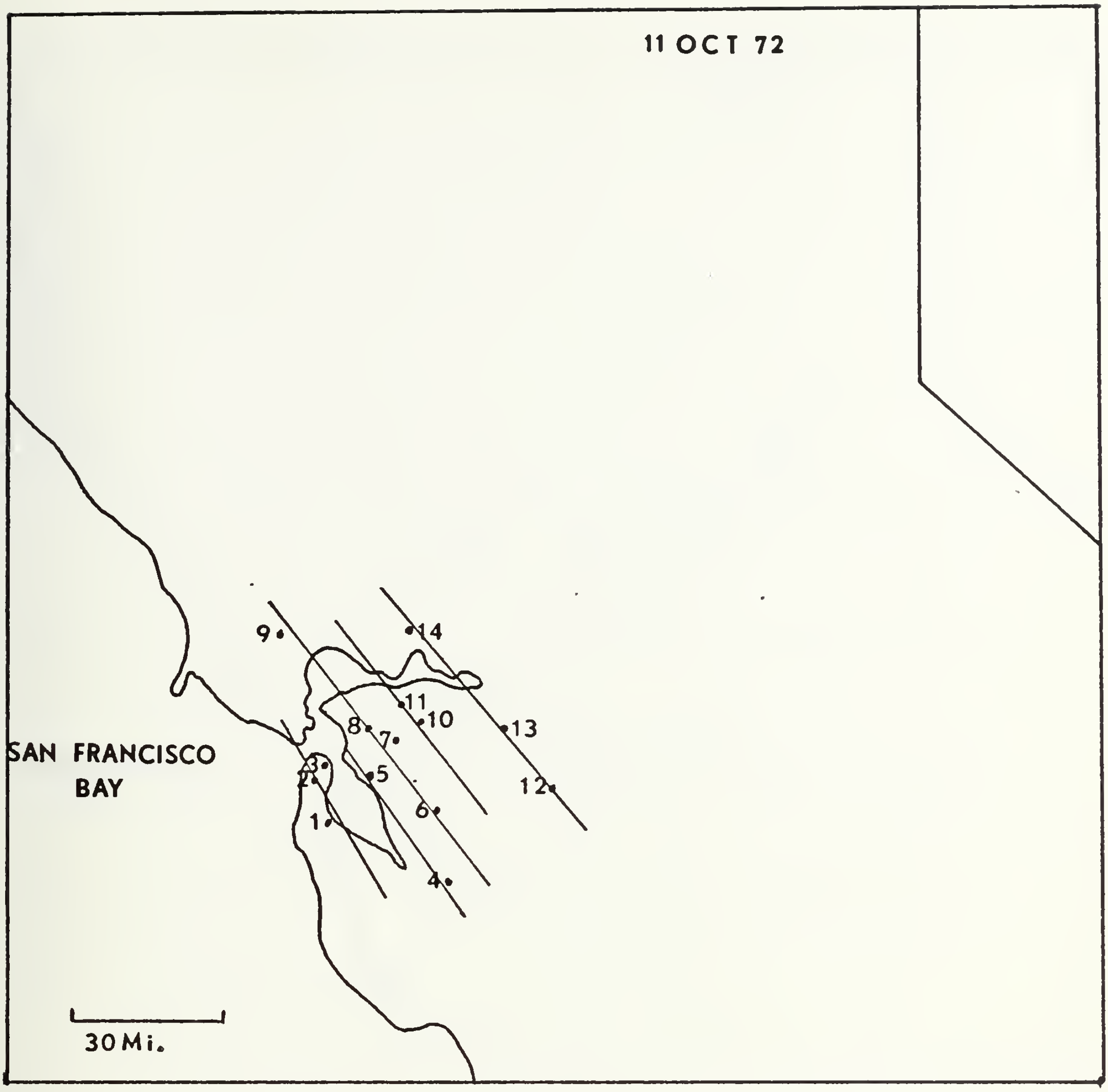

Figure 21. Hourly Rain Gauge Reporting Stations Selected for Rainfall Cross Sections Perpendicular to the 500 mb Flow.

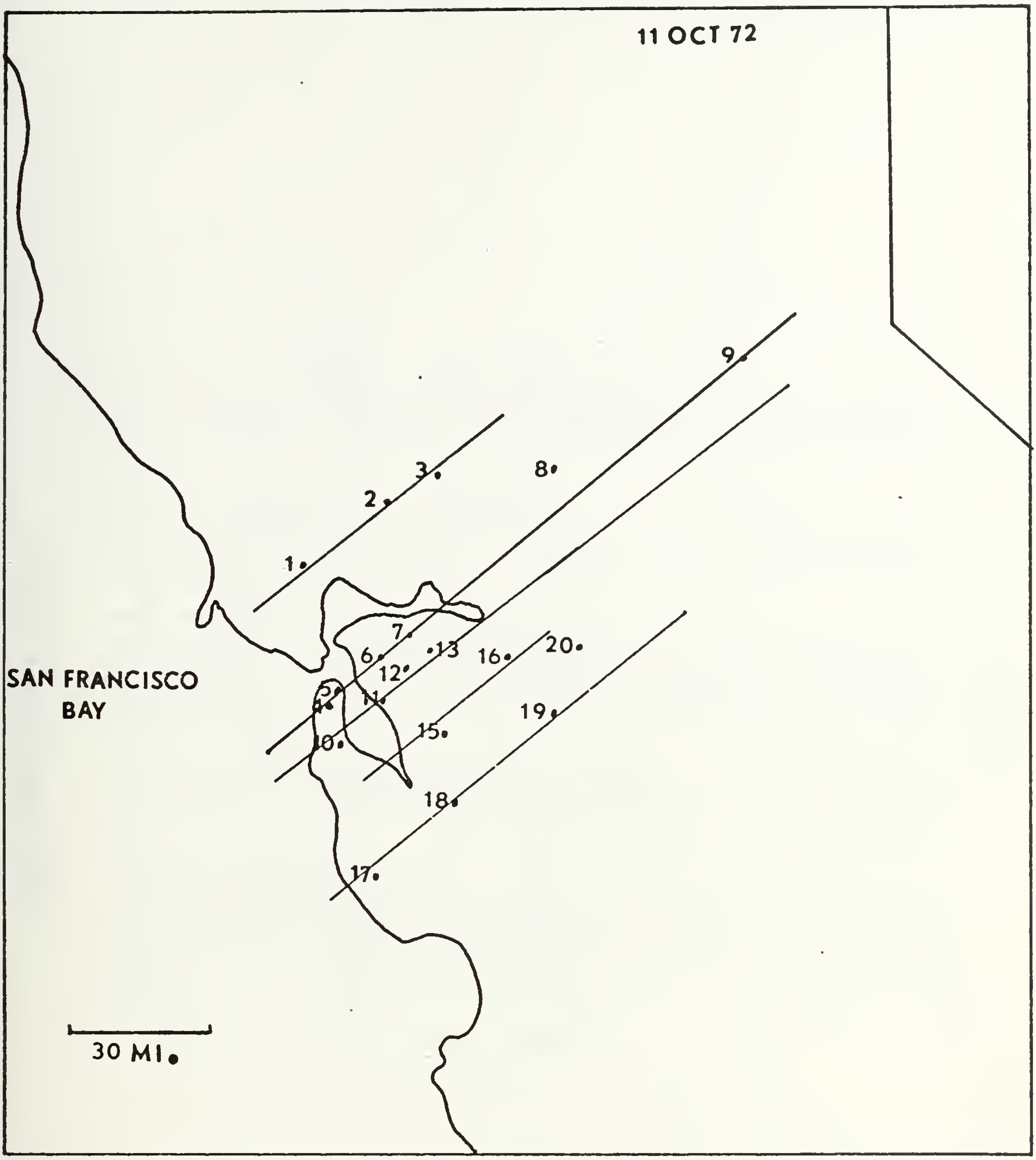

Figure 22. Hourly Rain Gauge Reporting Stations Selected for Rainfall Cross Sections Parallel to the 500 mb Flow.

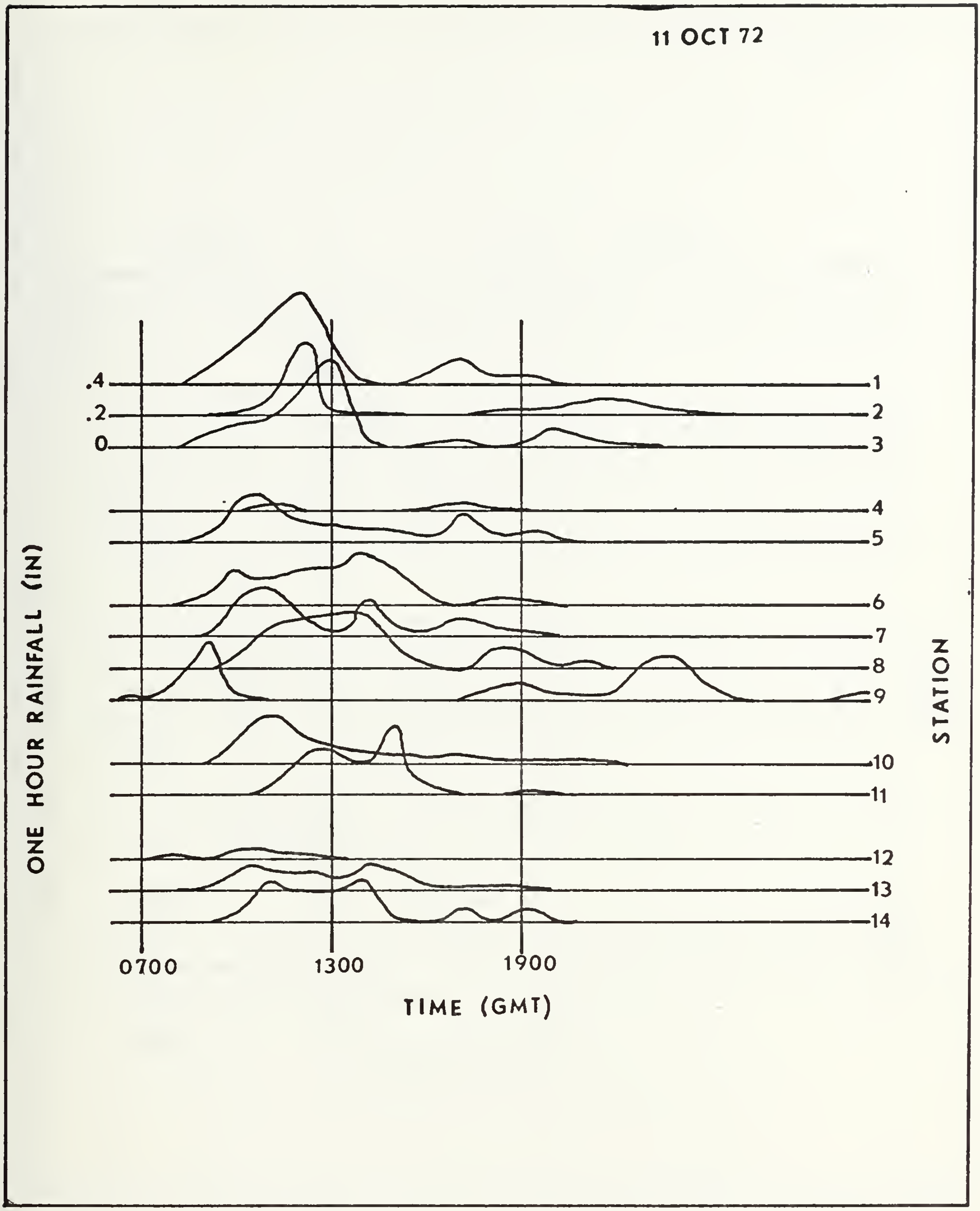

Figure 23. Hourly Rainfall Cross Sections Perpendicular to the 500 mb Flow at Stations Indicated in Figure 21.

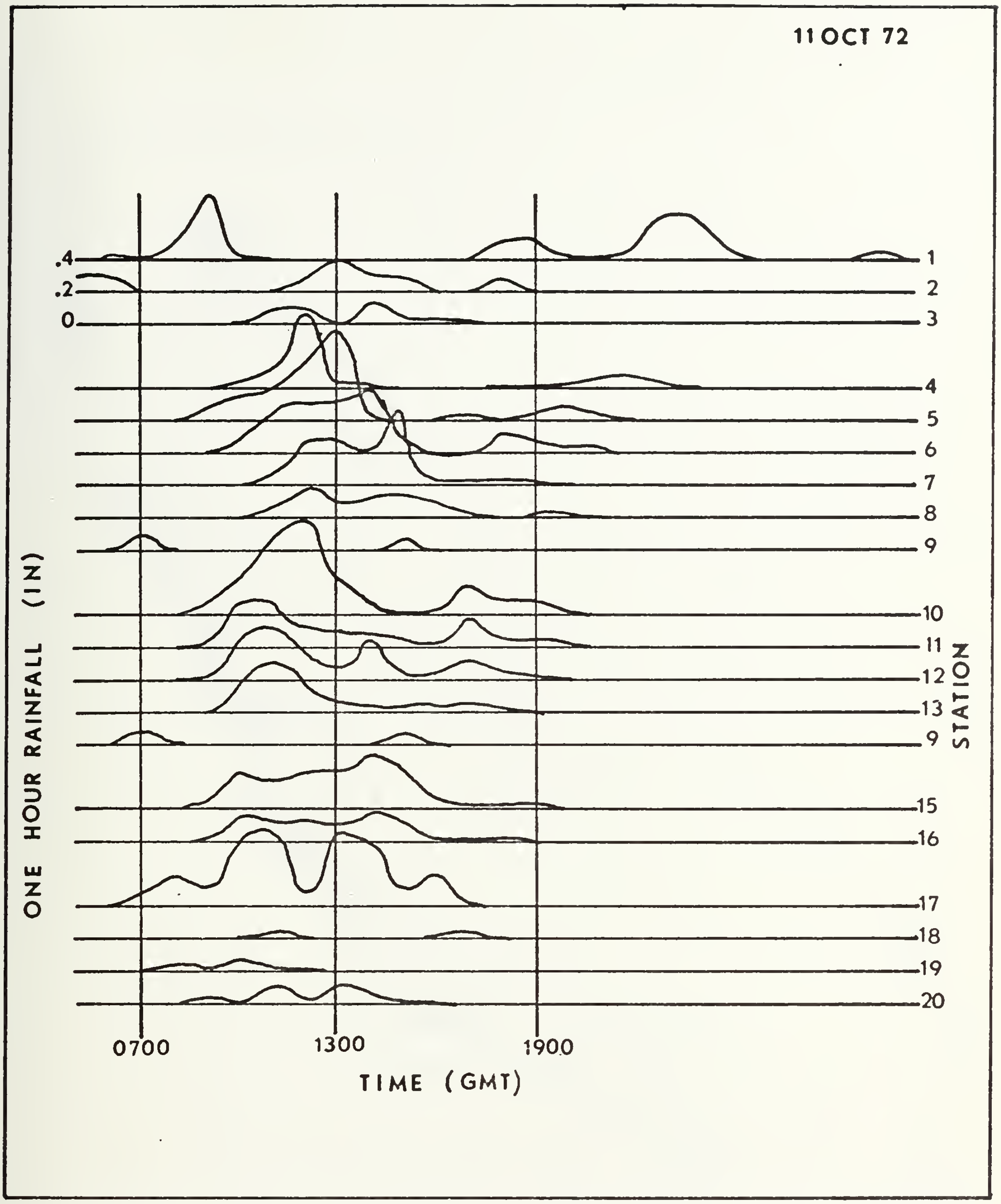

Figure 24. Hourly Rainfall Cross Sections Parallel to the 500 mb Flow at Stations Indicated in Figure 22.

Figure 25. 48-Hour Total Precipitation for 13-14 November 1972 (1.0 in isohyets).

Figure 26. 48-Hour Total Precipitation for 15-16 November 1972 (1.0 in isohyets).

Figure 27. 48-Hour Total Precipitation for 17-18 January 1973 (1.0 in isohyets).

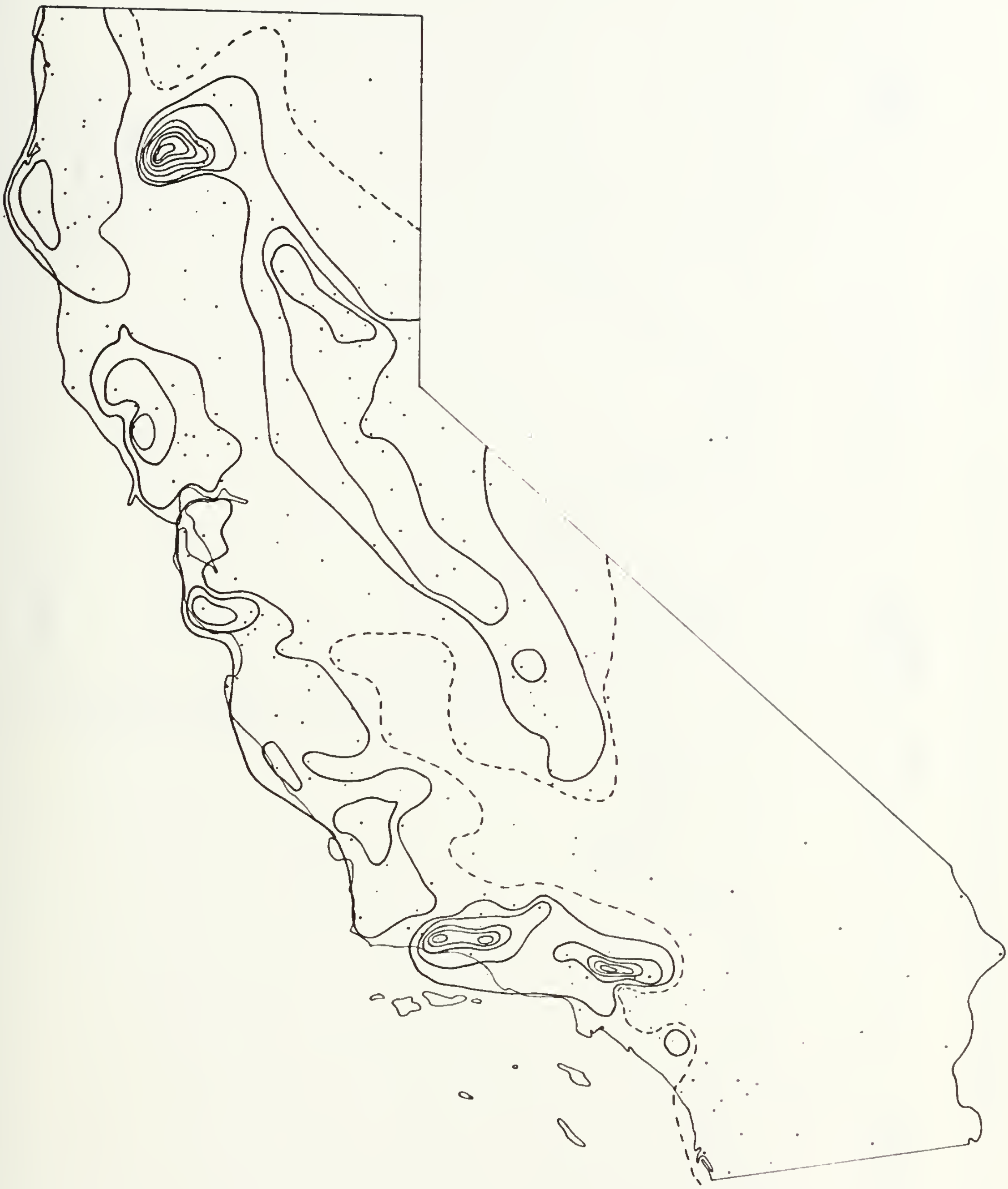

Figure 28. 48-Hour Total Precipitation for 9-10 February 1973
(1.0 in isohyets with 0.5 in isohyet a dashed line).

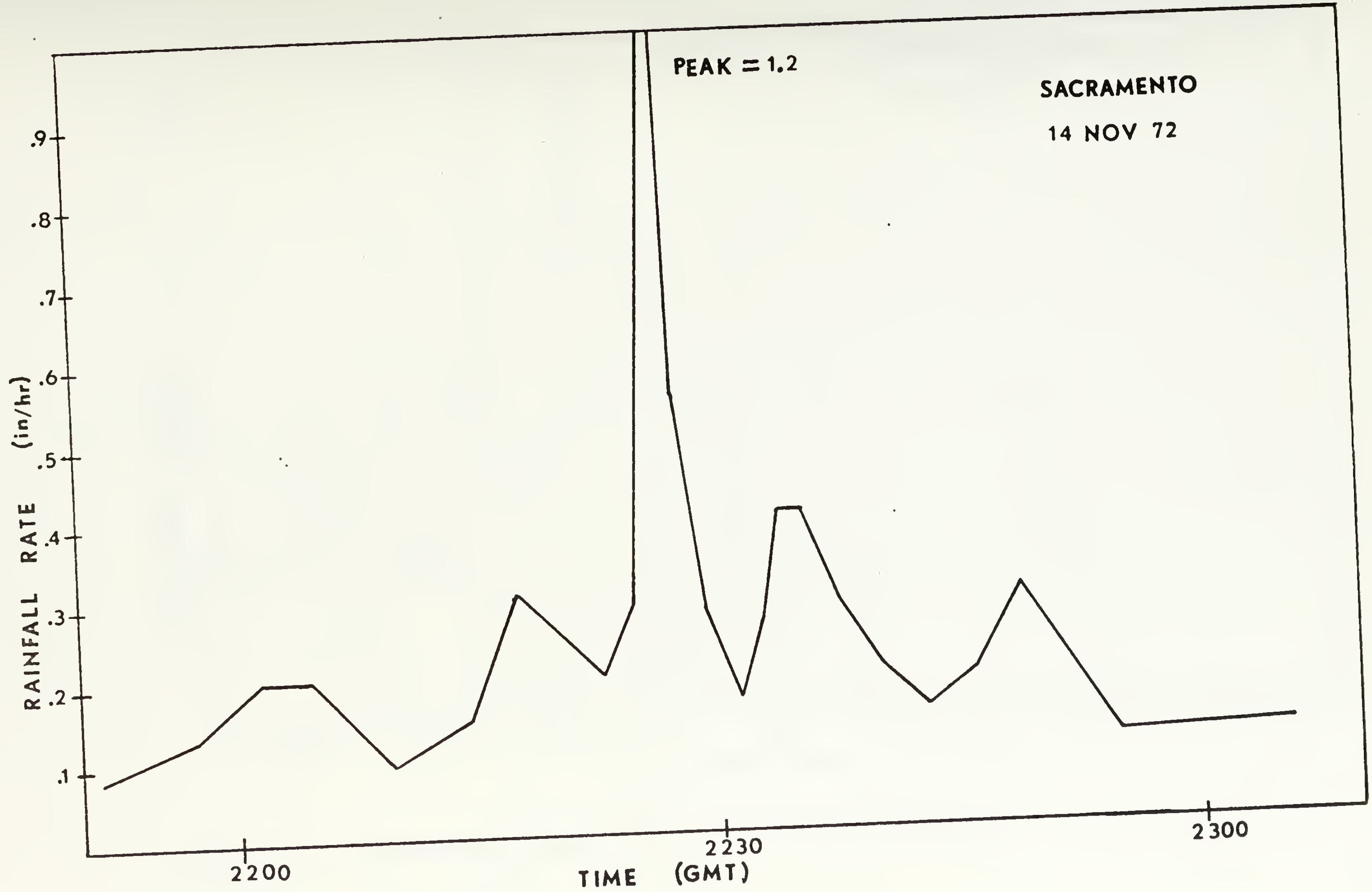

Figure 29. Tipping-bucket Rain Gauge Trace for Sacramento, California.

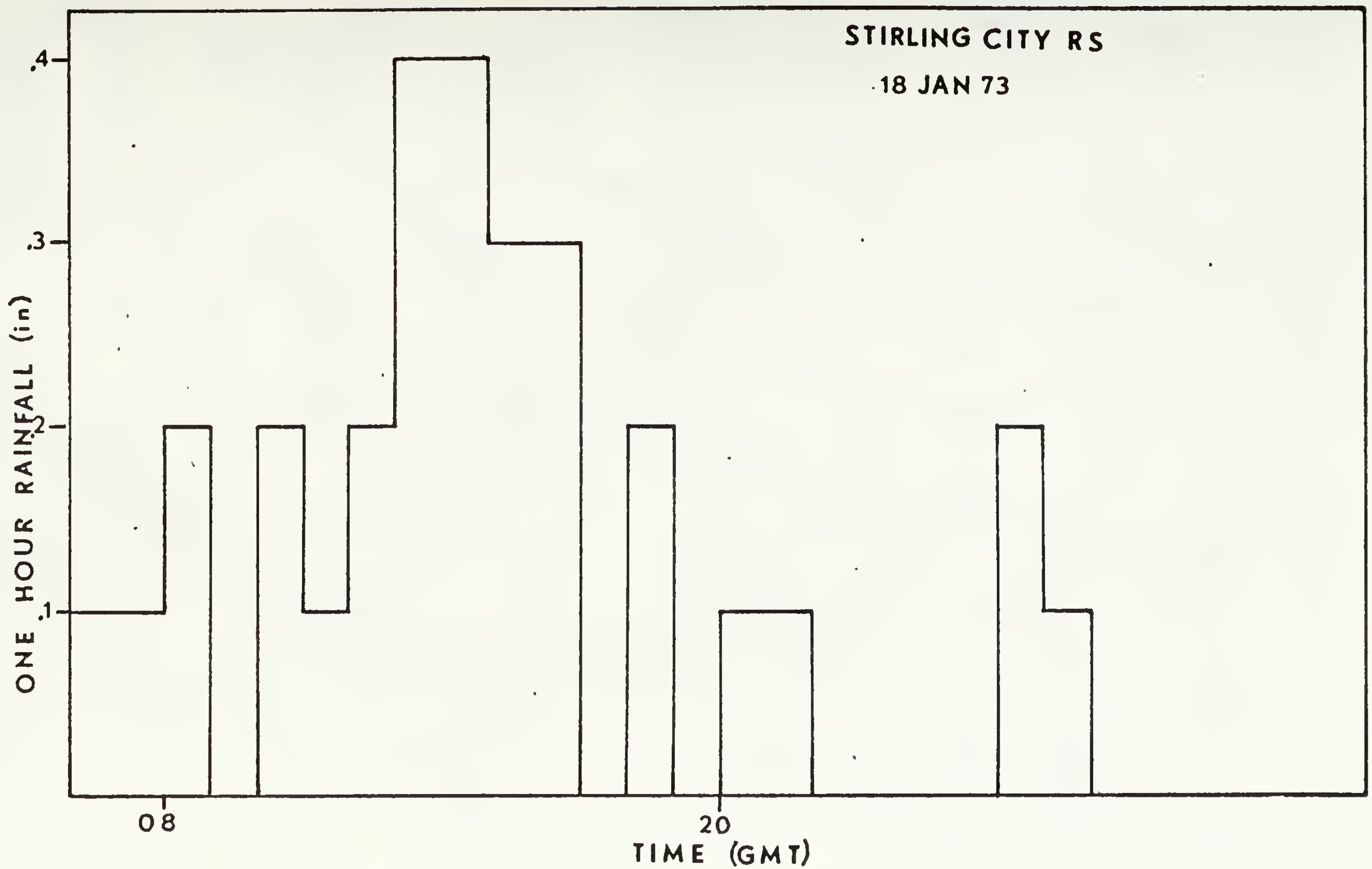

Figure 30. Histogram of Hourly Rainfall at Stirling City RS.

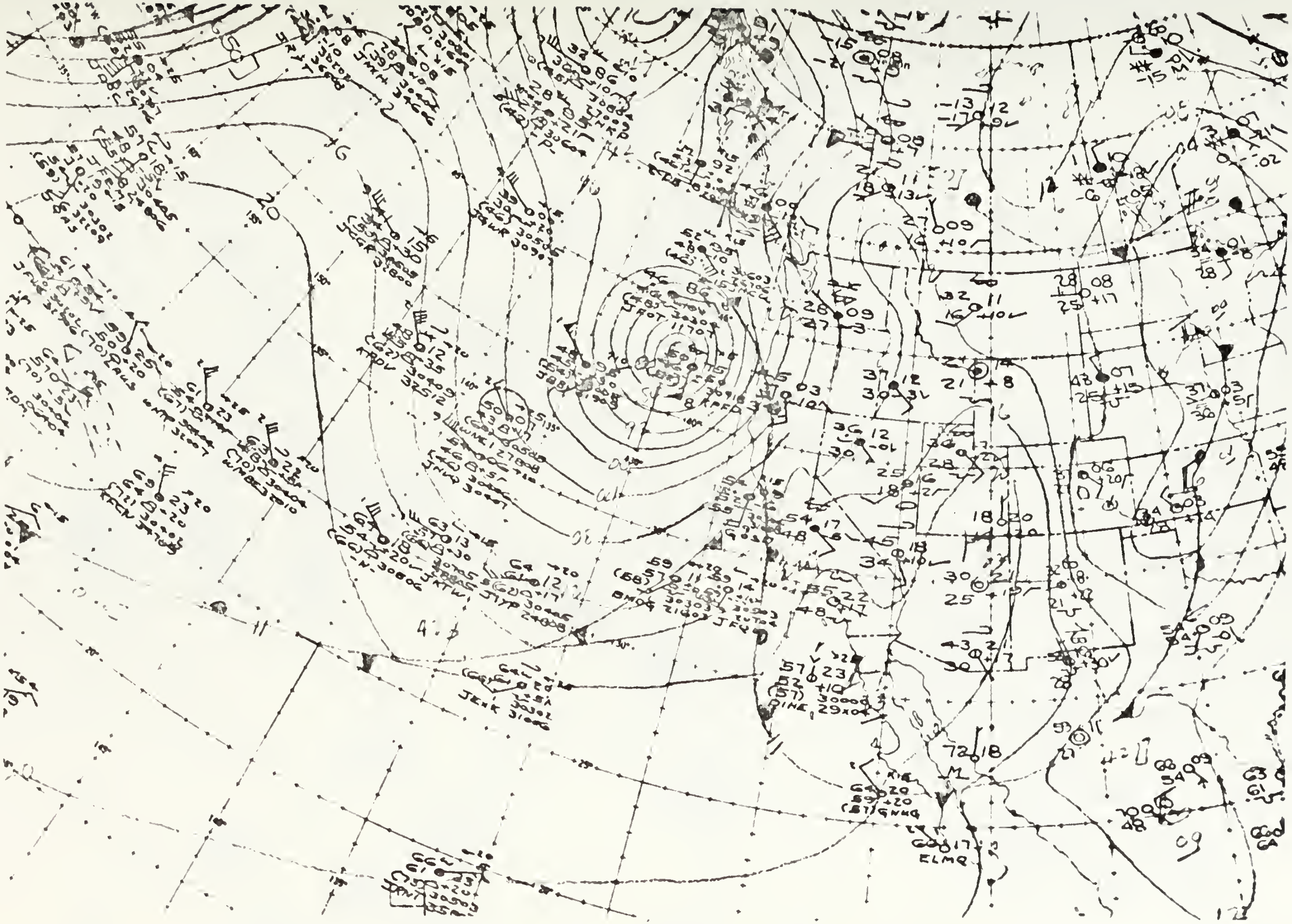

Figure 31. Surface Synoptic Chart for 0600 GMT 18 January 1973.

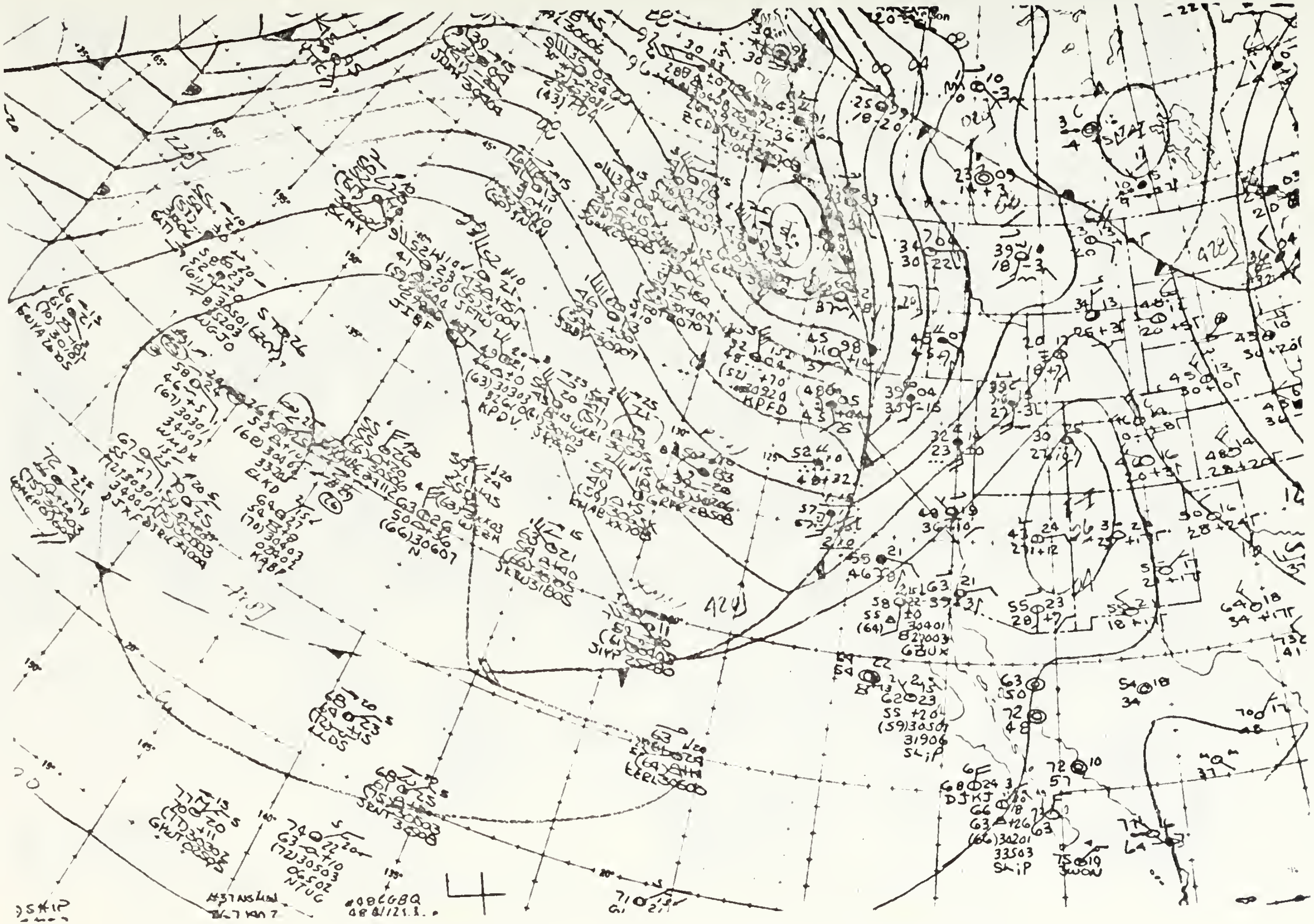

Figure 32. Surface Synoptic Chart for 1800 GMT 18 January 1973.

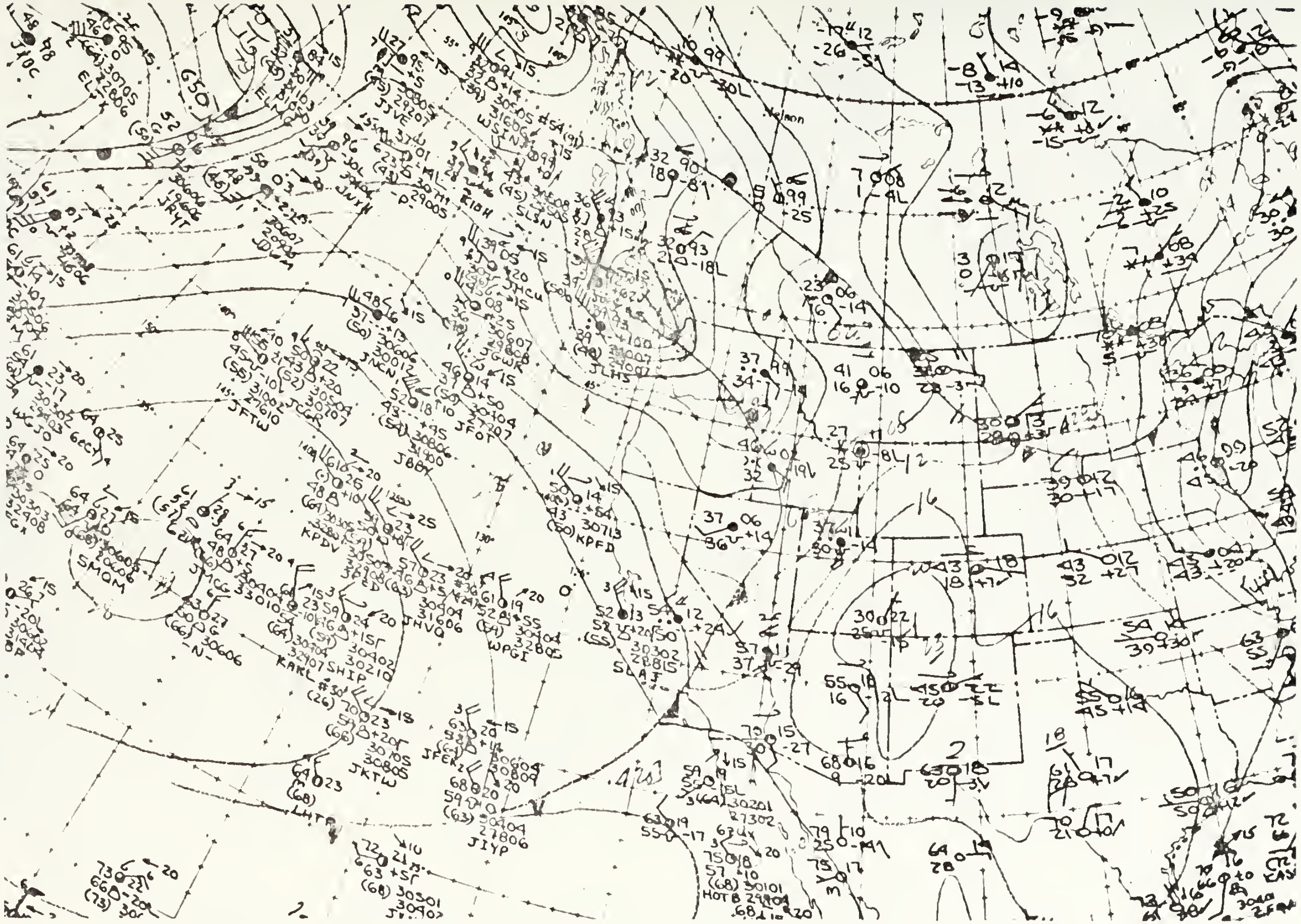

Figure 33. Surface Synoptic Chart for 0000 GMT 19 January 1973.

Figure 34. One-Hour Precipitation Totals, 0800-0900 GMT on 18 January 1973 (0.1 in isohyets with frontal position indicated by dashed line).

Figure 35. One-Hour Precipitation Totals, 1100-1200 GMT on 18 January 1973 (0.1 in isohyets, with frontal position indicated by dashed line).

Figure 36. One-Hour Precipitation Totals, 1400-1500 GMT on 18 January 1973 (0.1 in isohyets, with frontal position indicated by dashed line).

Figure 37. One-Hour Precipitation Totals, 1700-1800 GMT on 18 January 1973 (0.1 in isohyets, with frontal position indicated by dashed line).

Figure 38. One-Hour Precipitation Totals, 200-2100 GMT on 18 January 1973 (0.1 in isohyets, with frontal position indicated by dashed line).

Figure 39. One-Hour Precipitation Totals, 2300-0000 GMT on 18 and 19 January 1973 (0.1 in isohyets, with frontal position indicated by dashed line).

Figure 40. One-Hour Precipitation Totals, 0200-0300 GMT on 19 January 1973 (0.1 in isohyets, with frontal position indicated by dashed line).

Figure 41. One-Hour Precipitation Totals, 0500-0600 GMT on 19 January 1973 (0.1 in isohyets, with frontal position indicated by dashed line).

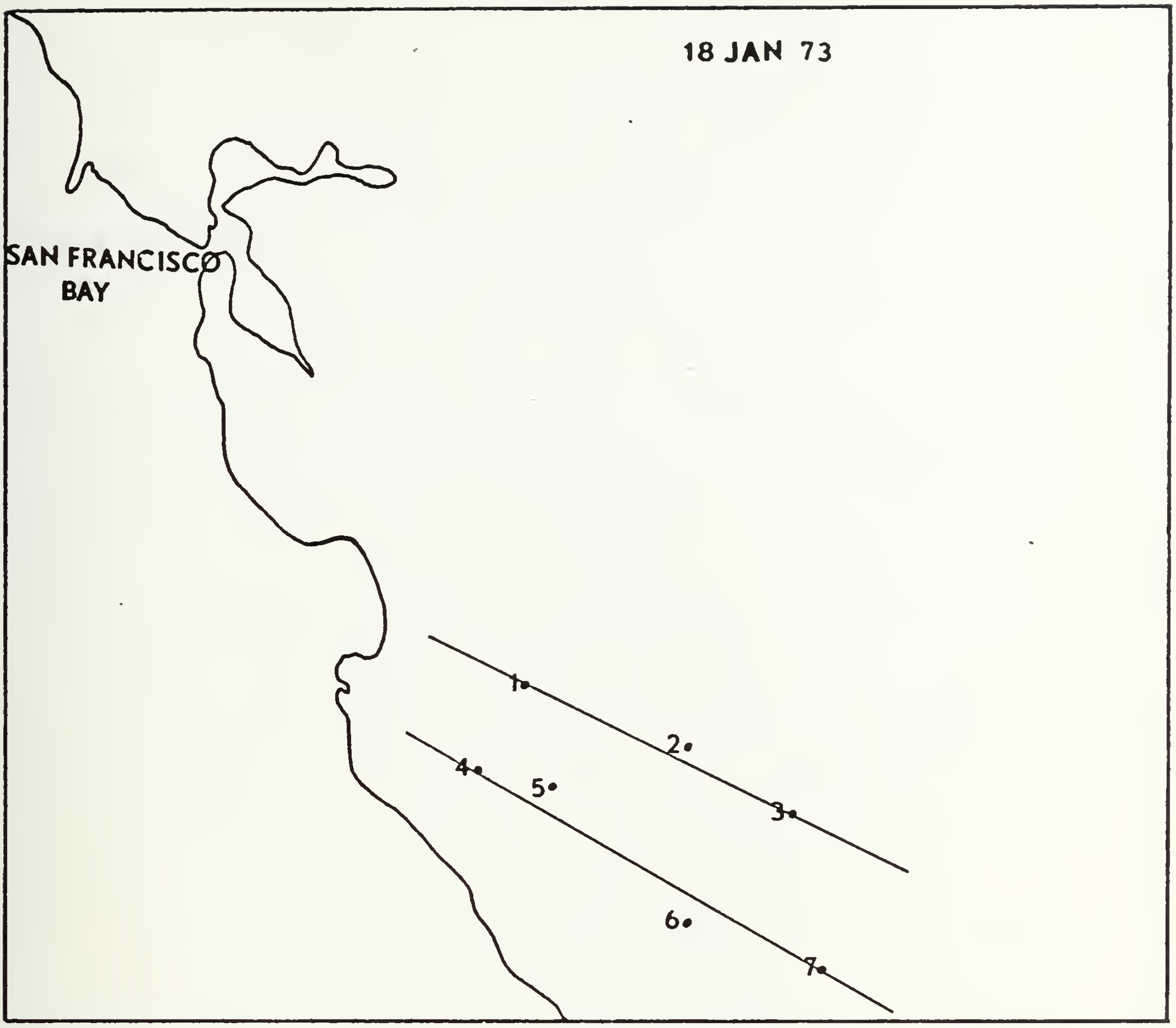

Figure 42. Hourly Rain Gauge Reporting Stations Selected for Rainfall Cross Sections Perpendicular to the Surface Frontal Axis.

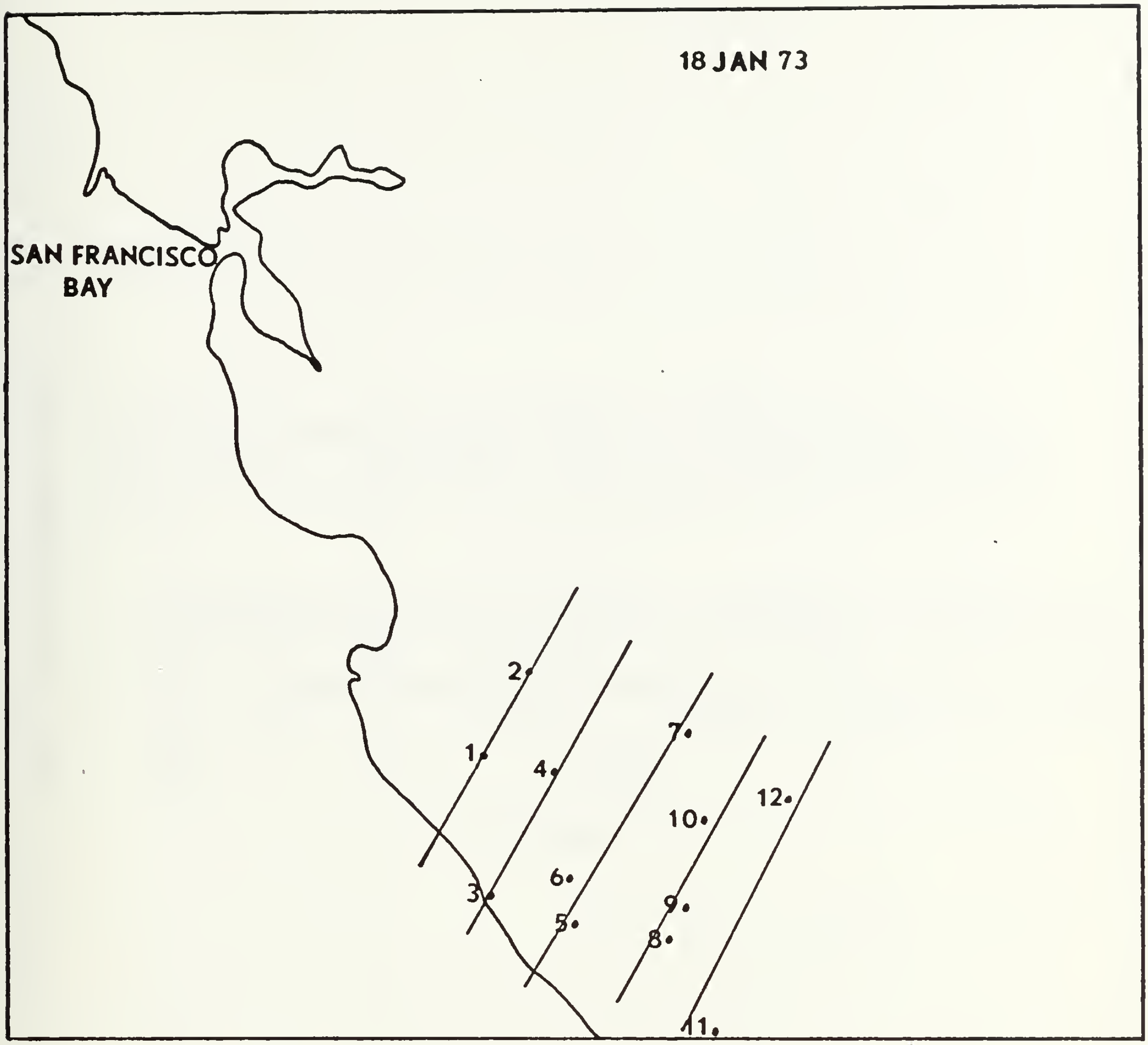

Figure 43. Hourly Rain Gauge Reporting Stations Selected for Rainfall Cross Sections Parallel to the Surface Frontal Axis.

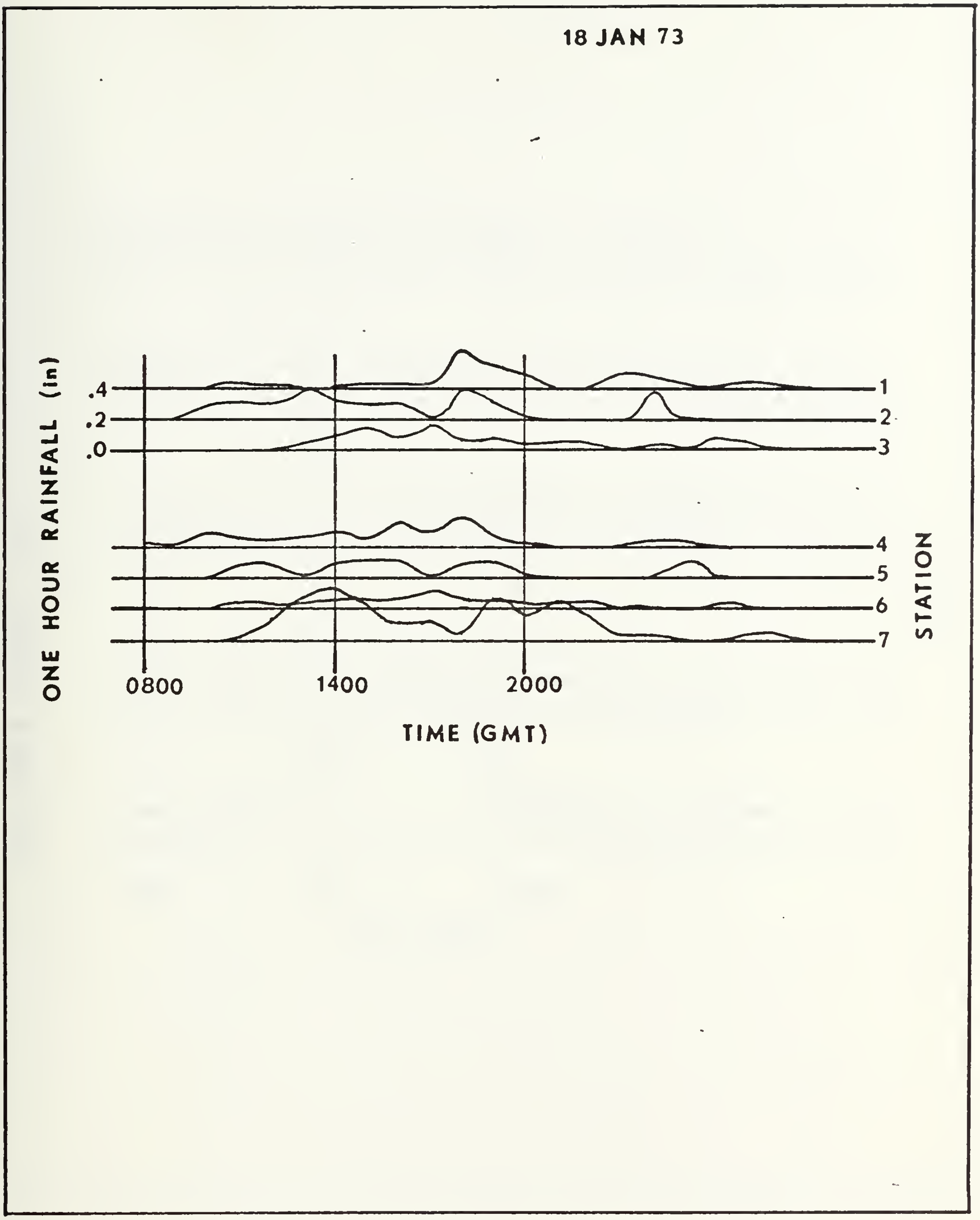

Figure 44. Hourly Rainfall Cross Sections Perpendicular to the Surface Frontal Axis at Stations Indicated in Figure 42.

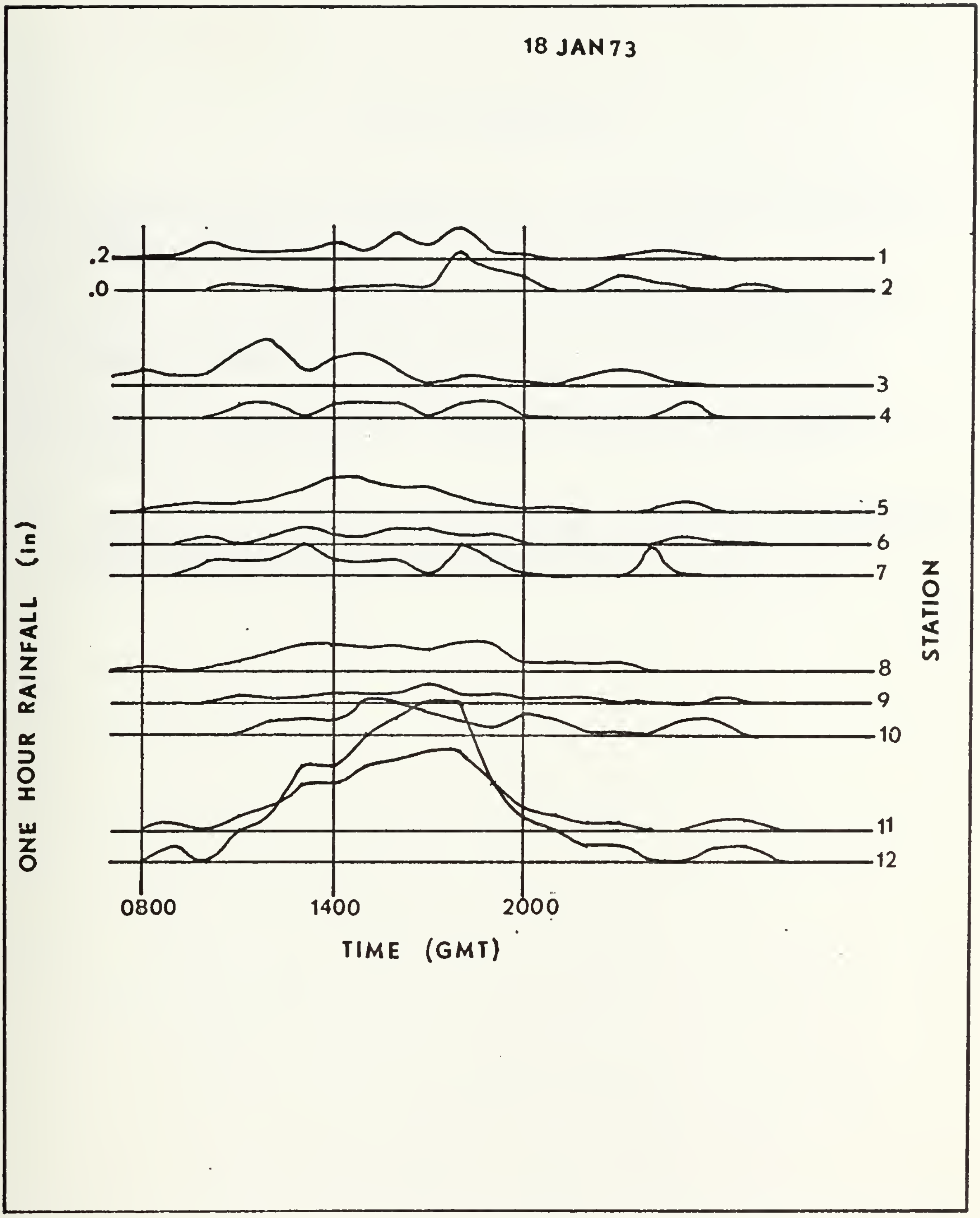

Figure 45. Hourly Rainfall Cross Sections Parallel to the Surface Frontal Axis at Stations Indicated in Figure 43.

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The rainfall patterns in California, produced by six storms of the 1972-1973 winter storm season, were analyzed in detail in order to determine the mesoscale distribution of precipitation with respect to the larger-scale synoptic systems.

It was found that the structure of precipitation patterns primarily reflected orographic influences rather than mesoscale circulation features intrinsic to the larger-scale system. Heaviest amounts of rainfall were

concentrated primarily along the major mountain ranges with much lesser amounts in the interior valleys.

Storms with fronts (Class II) produced more precipitation in the inland valleys and more convective type precipitation than storms without well defined fronts (Class I). Storms with fronts exhibited geographically fixed bands of precipitation that paralleled the surface front. An elongation of precipitation in the direction of the 500 mb flow was found in one case study.

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c.1 The mesoscale distribution of rainfall in California rainstorms.